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RAIL TRANSPORT OF SOLID WASTES

AMERICAN PUBLIC WORKS ASSOCIATION

PREPARED FOR
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The report documents results of a preliminary study to determine the technical-economic feasibility of hauling solid wastes by rail from urban areas to remote disposal sites. The rationale for a rail-haul system is discussed and various elements of the system, or factors influencing the practicality of rail-haul, are examined. These include: transfer stations and related refuse handling and compaction equipment; the position of railways in freight transport in the United States; suitability of various types of rolling stock for hauling refuse and other solid wastes; train configuration; and estimated costs. Consideration is given to implications of the rail-haul concept for operation of disposal sites, including use of strip-mine areas. Organizational, financial, and legal bases for transporting solid wastes by rail are outlined. The report includes numerous tables, diagrams, and maps.

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1973

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FOREWORD

Rail transport of solid waste is one of the most widely discussed options for solving the problems confronting large urban centers of the United States, where waste generation is increasing at the same time that close-in, low-value land for waste disposal is being depleted. Currently no rail systems are being utilized to transport solid waste from these centers to potential disposal sites. Because of the interest in the concept and the absence of operating systems, the Office of Solid Waste Management Programs (OSWMP) supported this study to assess the feasibility of rail transport of solid waste.

The study report, as an initial survey of the rail-haul concept, affords some basic insights into this relatively recent innovation in solid waste handling. As the first consolidated body of information on rail haul, it also serves as an elementary reference document.

Although OSWMP notes many areas in which our interpretation varies from that of the authors, the report, including references, is published here without editorial or technical change. Persons with more than a cursory interest in the report are encouraged to analyze carefully the data presented, including the methods employed to obtain the data, and then interpret results reported discerningly.

The Office of Solid Waste Management Programs believes that solid waste rail haul is a politically, economically, and environmentally viable concept. To stimulate the application of this concept, OSWMP is sponsoring new demonstration projects to establish actual operating rail-haul systems.

--SAMUEL HALE, JR.
Deputy Assistant Administrator
for Solid Waste Management

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RAIL TRANSPORT OF SOLID WASTES

SUMMARY AND RECOMMENDATIONS

Summary

How to dispose of the mounting quantities of solid wastes produced in urban areas has become one of the nation's most pressing problems. Land for close-in sanitary landfills is rapidly being filled up and new landfill areas in a growing number of cases are not within an economical truck-haul distance from the point of generation. Incinerators in many areas have been either closed or forced to operate at reduced rates in order to minimize air polluting emissions. Composting has not become feasible for most areas due to the lack of an adequate market for the product.

The concept of the "three r's," reuse, recycle, and reclamation has not yet been generally adopted. An apparent major deterent has been the difficulty in gathering at one location sufficient quantities of wastes to create a source of second-hand materials large enough to enable an economical recycling operation to be undertaken.

An evaluation of alternatives led the American Public Works Association to initiate a feasibility study to determine if railroads could be advantageously utilized as a low cost, long-haul method of transporting solid wastes to disposal or reclamation sites far removed from high-density urban areas. The study was jointly financed by 22 local governmental agencies, the Penn Central Railroad, and the Solid Waste Management Office of the U.S. Environmental Protection Agency. Phase I of the study was begun in April 1967 and completed in March 1970; however, work was suspended on the project for a period of approximately eighteen months to conduct a separate study of high-pressure compaction and baling of solid wastes because this appeared to be a highly important part of an optimum solid-waste rail-haul system.

An interim report dated October 1968 was widely distributed and a complete report on Phase I was distributed to study sponsors in March 1970. In October, 1970, Phase II of the study was initiated. This report presents the consolidated findings of both Phases. Originally Phase II was planned to continue feasibility studies and to serve as a catalyst for the establishment of one or more demonstration projects for the various building blocks needed for an integrated rail-haul system. Phase III was to complete the feasibility study after evaluating the operation of a pilot solid-waste rail-haul system; assuming, of course, that preliminary studies indicated that an investment in a pilot system was warranted. Press manufacturers, railroads and other interested groups were kept informed of the research findings and encouraged to conduct independent developmental work on the rail-haul concept. Since the compaction and baling demonstration project was conducted prior to the completion of Phase I and since considerable developmental work was being done by the private sector, it was decided to make more in-depth studies of some elements of the system and to complete the preliminary feasibility study, under Phase II, without actually evaluating a pilot operation. This would provide public agencies with current information on the potential of rail-haul of solid wastes and the problem areas involved without having to wait for a totally integrated demonstration project to be funded and completed.

This report, therefore, explores the feasibility of using rail haul as an integral part of a solid-waste management system. Five major studies were conducted concerning:

1. Transfer stations and refuse processing—how to get the wastes into the system;
2. Rail Transport—how to get the wastes to the point of disposal;
3. Disposal Operations—how to dispose of large volumes of wastes;
4. Administration—authority of states to establish a regional or area-wide authority which might operate a system, and
5. Public health and environmental control—how to overcome any adverse environmental problems associated with a rail-haul solid-waste disposal system.

The principle conclusion of the study is that rail transport of solid wastes is not only feasible but that no "breakthroughs" or major technological improvements would be necessary to implement a rail-haul landfill operation at a price competitive to disposal costs being paid by many cities in metropolitan areas.

As reported in detail in the report, solid wastes may be either processed, i.e. baled or shredded, or unprocessed, i.e. as obtained from the collection vehicle. The economic advantage of processing the wastes can be determined from an analysis of: 1. the transport function where the cost of equipment and haul is involved; 2. the disposal function where the amount of space, type of equipment, speed of operation, and cover material requirements must be evaluated; and 3. the processing operation and related facilities required at the transfer stations. A related consideration is the degree of recycling of the wastes which is or may become feasible, possible methods for separating the components to be recycled, and at what point—the point of origin, the transfer stations, or the point of disposal—the separation of components for the recycling operation will be done.

Clearly, no one cost analysis can incorporate the multitude of variables which might be included in a rail-haul system.

The basic system which was chosen for analysis utilizes:

1. Sanitary landfill as the means of ultimate disposal because, under current conditions, it offers the most promise for an economical and perhaps beneficial (through land reclamation) disposal method.
2. Shipment by rail because of its inherent ability to move high density freight over long distances at low cost. To maximize the economic advantages of rail, it was found that:
   a. Shipments should make full utilization of existing equipment, i.e. loads of 100 or more tons per rail car are desirable.
   b. Shipments per train should be at least 1,000 tons,
   c. Shipment schedules should fully utilize equipment—100, 200, or 300 trips per year, and
   d. Shipments should generally be by equipment used only for haul of solid wastes to increase equipment utilization and ensure dependability.
3. One-way haul distances of 100 miles, since most intrastate systems can be operated on this basis;
4. One 8-hour shift per day be used for the operation of both the transfer station and disposal facility.

The hours of operation for a transfer station will, in practice, vary widely depending upon the source and nature of wastes received. However, for the basic system the one-shift operation was chosen.

An important consideration which could not be discussed in detail is railroad pricing structure. The railroad costs which have been utilized throughout this report have been based upon actual cost as well as accelerated depreciation and standard allowances for overhead and profits. The Interstate Commerce Commission early in 1971 reaffirmed its previous position that "transportation of trash and garbage, which has no property value, solely for the purpose of disposal will continue to be not subject to economic regulation by the ICC." However, should the same material be hauled to a recycling facility, the ICC has announced that it intends to extend its jurisdiction to the setting of rates for such hauls.

Thus, pricing by individual railroads will depend upon the competitive position of the railroad, the railroad's judgment of the ability-to-pay of the agencies to be served, the railroad's estimate of the cost of alternate available methods of disposal to the public agencies, and applicable railroad operating costs, as determined by how the railroad allocates costs in its bookkeeping system and local labor contracts.

It should be noted, however, that present conditions of rail plant and railroad labor practices and their impact on the rail-haul of solid wastes could cause an increase in rail-haul system cost. There is a catch-up demand in equipment and facility maintenance, and some labor regulations do not favor an increase in productivity. In addition, there are the unpredictable effects of continued inflation and the adverse effects of certain governmental transportation policies and regulations—their rate making activities, failure to adjust service requirements to changes in demand, and perpetuation of outmoded work rules.

Balanced against these general conditions, however, are the favorable arrangements which have been made with railroads and railroad brotherhoods to permit proposals for rail-haul service to be made to several communities. Brotherhoods, in some instances, have agreed to experimently waive some rules because the regular nature of the contemplated transfer movement and the volume contemplated, represents both "new work" and public service work.

The benchmark costs presented in this report provide public agencies with a basis for evaluating the reasonableness of proposals submitted for rail transport of solid wastes. Table 1, Summary of Costs for Rail-Haul of Solid Wastes, presents an overview of the component costs of the various items which make up the total cost of the various rail-haul systems. The total cost, exclusive of land acquisition, environmental controls and site development, was found to vary from $5.60 to $7.62 per ton for baled refuse, $6.16 to $9.20 per ton for unprocessed refuse, and $7.32 to $10.60 per ton for shredded refuse. Each system envisions the landfill disposal of 1,000 tons of refuse per day on a six day per week basis.

Three processing methods, chemical dissolution,

TABLE i
SUMMARY OF COSTS
for
RAIL-HAUL OF SOLID WASTES

	Item	Cost per ton–Owning and Operating (excludes financing and amortization)		
		High-Pressure Compaction	Unprocessed	Shredded
1.	Transfer Station [1]	$2.00–$2.50	$1.60–$2.10	$2.40–$3.10
2.	Rail Cars	.12– .34	.25– .75	.25– .75
3.	Motive Power			
	a. locomotive	.17– .51	.24– .71	.24– .71
	b. locomotive maintenance	.06	.06	.06
	c. fuel	.15	.15	.15
	d. labor	.20– .30	.20– .30	.20– .30
4.	Track Cost	.30	.30	.30
5.	Landfill			
	a. operation	.60– .90	1.20. 1.80	1.20– 1.80
	b. haul to disposal	.40	.40	.40
6.	Subtotal (1-5)	$4.00–$5.46	$4.40–$6.57	$5.20–$7.57
7.	Taxes and Supervision @ 25%			
	Contingency @ 15%	1.60– 2.16	1.76– 2.63	2.12– 3.03
8.	Total	$5.60–$7.62	$6.16–$9.20	$7.32-$10.60

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[1] 500 ton/8 hour shift, 6 day week. Excludes land acquisition, environmental controls, and site development.

size reduction, (i.e. shredding) and compaction were investigated. The substudy on chemical processing was rather brief, since it was found that a suitable total system would require extremely complex operations, extended research efforts and perhaps a very long development lead time. Information on this substudy is not given in the report.

The substudy of size reduction for rail-haul considered many variables. The findings indicate that the volume reduction of solid wastes by size reduction with existing equipment and excluding any subsequent compaction, ranges from less than 2:1 to about 3:1. Furthermore, to handle most of the residential and commercial refuse, including oversized items, from urban solid waste disposal systems, size reduction is, with existing equipment, estimated to cost upwards of 80 cents to $1.00 per ton on an 8-hour, one-shift per day basis. This cost covers only straight depreciation, maintenance, and power, while excluding financing charges, return on investment and labor.

A demonstration project on high-pressure compaction and baling of solid wastes was conducted under contract by the APWA as a companion study with the support of the City of Chicago and the Environmental Protection Agency, Solid Wastes Management Program. The demonstration project resulted from information developed in exploratory compaction tests conducted under the rail-haul study. A separate report on that project has been prepared.

The demonstration project showed that high-pressure compaction at about 2,000 to 3,000 psi produces stable high-density bales of residential/commercial solid waste mixtures suitable for rail transport of up to 700 miles. The average density of the bales ranged from 60 to 80 lb/cu. ft. The cost, including straight depreciation, maintenance, and power, but excluding financing charges, return on investment and labor are estimated at about 40 cents per ton based on an 8-hour, one-shift per day, operation.

The Tezuka refuse compaction process, developed in Japan, was also analyzed by the APWA. A report on the results of the analysis was prepared prior to conducting the compaction and baling project and was published by the U. S. Bureau of Solid Waste Management.

Rail Transport

The use of rail-haul as an integral part of a solid-waste disposal system was found to offer a great variety of alternatives for system implementation and operation. Railroads represent the leading mode of transportation for the movement of freight and serve all major population centers in the nation. In addition, an analysis of rail lines indicates that they lead through many sparsely populated and economically underdeveloped areas where suitable landfill disposal sites may be found.

The rail car analyses covered all types of cars including flatcar container systems. A load density of about 50 pounds per cubic foot is generally needed to achieve full utilization of the weight-volume capabilities of rail-cars.

The train analyses covered many configurations. The order of magnitude data indicate for 1969 that, with trains dedicated to solid waste, a 100-mile shipment with a payload of 600 tons per train, may cost $5.60 per ton for a load-density of 10 pounds per cubic foot (270 pounds per cubic yard) or $2.20 for a density of 70 to 80 pounds per cubic foot. For a payload of 1,200 tons per train, the cost would approximate $4.25 and $1.65 respectively. These costs are based on railroad-owned freight cars.

The rail transport analyses stress unit-train and dedicated train economics. Areas supplying 1,000 or more tons per day have been tentatively identified as rail-haul anchor communities.

The potential volume for solid-waste rail-haul was found to be quite large. Assuming an initial shipment of one ton per capita per year, the standard metropolitan areas served by the Penn Central Railroad might, for example, supply more than 68 million tons of solid waste. This amounts to more than 1.3 million tons per week or 217,000 tons per day on the basis of 312 working days per year. A stringent enforcement of environmental control regulations which would close some marginal disposal facilities might increase this tonnage by 10 to 15 percent.

The rail-haul system network analyses indicated attractive opportunities for solving waste disposal problems on an intrastate or, if desired, interstate basis. For example, through utilization of the existing rail network, it may be possible to solve for many years, about 70 to 80 percent of the solid waste disposal problems in the States of Illinois, Indiana, Ohio, Michigan, Pennsylvania, and New York. The analyses suggest further that this might be accomplished by the establishment of only two to three statewide disposal sites per state. Finally, rail-haul was found to greatly increase flexibility in the selection of disposal sites inasmuch as the cost increase per mile of haul is very low beyond a minimum distance.

To dimension the competitive feasibility of solid-waste rail-haul, it was necessary also to consider other modes of long-distance transport such as barges and truck-trailers. Barging and trucking operations can be analyzed and evaluated within the context of many performance models. Within the constraints of the present analyses, i.e. a 1,000-ton/one 8-hour shift per day operation, daily removal, a 100 mile one-way trip and dedicated service, trucking was found to be significantly more and barging slightly less expensive than rail-haul.

The long-term commitments that could be required for rail-haul systems makes it necessary to consider the potential influence of salvage and recycling on both composition and volume of the solid wastes. It was found that salvage or recycling operations could be conducted *before or after* the rail transport and that the effects might be appreciable. Rail-haul as a system may be of great advantage for significant salvage developments by concentrating large amounts of refuse in remote locations where salvage operations would not adversely affect adjacent property uses.

Disposal Operations

Due to the possible network effects of a solid-waste rail-haul system, it could be necessary to operate sanitary landfills capable of handling 10,000 or more tons of solid wastes per day. The present analysis emphasizes, however, 1,000 tons per 8-hour shift operations in order to highlight the situation found, and to decide on rail-haul anchor systems.

The economy of scale analyses based on many reports indicate that existing landfill operations cost about $1.20 to $1.80 per ton at 1,000 tons per day with somewhat lower costs as the volume increases.

As shown in the compaction demonstration project, compacted solid waste bales may increase the utilization of landfill space by about 100 percent. Thus, the savings with respect to land use and earth moving are substantial if highly compacted wastes are used. The cost per ton for baled refuse was found to be about 60 cents to 90 cents per ton at 1,000 tons per day.

The on-site movement of solid wastes from the rail head to the point of disposal was found to represent the largest variable among the landfill cost elements. Movement distances of up to four miles were analyzed and it was found that solid wastes could be moved over such distances at a total cost of about 40 cents per ton.

The landfill analyses showed that, given a sufficient capacity, the sites which are suitable for existing landfills are also suitable for rail-haul landfills. In addition, and due to the large amounts of material involved, rail-haul could present substantial opportunities for major land reclamation projects. Based upon the material accumulation capabilities of rail-haul, such developments could be accomplished and become visible within a strikingly short period of time which, as a rule, was heretofore unachievable.

With respect to land reclamation, the possibility of disposing of solid wastes in abandoned as well as active strip mines was investigated. The findings indicate that the geographical location of coal mines is very favorable with respect to the location of many highly urbanized centers.

The landfill analyses suggest that the cost of landfilling baled refuse for a rail-haul system, may range in terms of 1971 cost data, from $1.40 to $1.82 per ton and that it is feasible to dispose of solid wastes in active strip mines at a cost of less than $1.50 per ton.

Administration

The planning, site acquisition, and contracting for services as well as the financing of a solid-waste rail-haul system will require that the system be owned and operated by either private industry or by a state, intrastate, or interstate agency. Private industry in recent months has indicated a willingness to provide complete disposal services upon receipt of wastes at a transfer station. However, there appears to be only a limited number of landfill locations which can be acquired by private industry with zoning or land use controls which would allow disposal operations. There may also be a reluctance on the part of many public agencies to become dependent upon one anchor community for the disposal operation inasmuch as they would be unable to exert administrative control over the operation. Thus, it appears likely that there will be a need for state solid-waste disposal agencies or large regional authorities with the power to contract, raise funds, and to exert the power of eminent domain.

Data gathered in 41 replies to a questionnaire sent to individual states indicates that most of them have some agency specifically charged with solid waste management responsibilities. In only half, however, is a single agency so charged; in the remainder responsibilities are shared with from one to dozens of state governmental agencies – apart from local governments. The principal agencies of 30 states reported their date of establishment; half were created in the last five years, and half of those in the single year 1970. Hence it is not surprising that relatively few have as yet been able to assemble such resources of staff, financial support and expertise as will enable them to deal authoritatively with their critical responsibilities.

Among the problems cited as likely to be encountered in initiating a solid-waste rail-haul operation were consideration of economics and public opinion. It was felt that these greatly outweigh those of a legal or technical nature. (It should be noted in passing that some legal barriers have been erected because of adverse public opinion.) Economic problems centered around a common core of costs (too high), volume of refuse (insufficient), and economic justification (as compared to alternatives). Respondents are in agreement that effective public relations, including educational efforts designed to project a good "image" of sanitary landfill (and operating practices to justify it) is essential to locating and utilizing disposal sites nearby or – via rail-haul – at distant locations.

PUBLIC HEALTH AND ENVIRONMENTAL CONTROL

In developing a solid-waste disposal system it is necessary to give considerable attention to public health, environmental control, and occupational health aspects with respect to all system elements. Essentially, the respective problems of unprocessed and physically processed wastes i.e. shredded and compacted, are of the same type as those found in other solid-waste disposal systems which use an enclosed transfer station, vehicles for long-distance transport, and sanitary landfills. However, some differences are introduced through processing. These are associated mainly with the use of heavy processing machinery as well as with changes in waste properties resulting from the physical treatment.

The collection and storage of the incoming, loose refuse in transfer stations requires the same environmental control measures recommended for well-run incinerators. Dust problems, if they exist, could be appreciably reduced through the use of paper or plastic sacks in refuse collection.

The processing section of the transfer in which the wastes are either compacted or shredded should incorporate dust, noise, odor, vector and leachant control. Dust is not produced during compaction, however, appreciable dust problems can be created during size reduction. The charging of non-sacked refuse into presses or size reduction equipment perhaps requires greater dust control measures than those applied in charging incinerators. Noise control measures may have to be implemented in both size reduction and compaction processing. Major sources of compaction process noise can be eliminated by a proper installation of the press and the use of soundproof pump enclosures.

In the overall, rail-haul transfer stations require the same provisions of good housekeeping as other enclosed solid-waste disposal facilities: active ventilation for use as needed, regular cleaning, drainage, fire control, and some regulation of the "in-house" temperature and humidity.

Biological activity can occur in both processed and unprocessed wastes during prolonged storage and/or during any type of long-distance transport. Prolonged standing of refuse cars in rail stations should be avoided because of odors and the wastes always should be covered or enclosed.

Considerable advantages appear to be gained in landfilling by the use of compacted solid waste bales: no blowing of paper in case of high winds, and reduction of the possibility of open or smoldering fires. Furthermore, it is also likely that, as a result of hindered water percolating through the bales in landfills, the release of gaseous and liquid contaminants from baled refuse will be less than from an equivalent quantity of loose wastes for a given period of time.

LARGER CAPACITY SYSTEMS

As previously stated, the report proposes as a minimum system, a 1,000-ton per one-8-hour shift per day operation. In principle, such an enlarged system can be provided in six ways:

1. by adding transfer stations, trains and landfills with capacities the same as the minimum system;
2. by adding transfer stations and trains in the capacities given but increasing the scale of operations at a single landfill site;
3. by adding transfer stations of the capacities given but increasing the net load per train as well as the scale of operations at the landfill site;
4. by operating the transfer stations of the capacity given two or three shifts per day coupled with an increase in the net load per train as well as in the scale of operations at the landfill site;
5. by increasing the basic capacity of the transfer stations as well as of the train, and landfill site; and
6. by combinations of the various scale-up elements indicated above.

Various scale-up possibilities are indicated in the report. For example, the various ranges of train net load as well as shipper and railroad owned freight cars are discussed. For landfills, data are given to show cost-trends related to the daily disposal tonnage.

RECOMMENDATIONS

Rail-haul has considerable merit in terms of solid-waste management, environmental control, and solid waste material recycling. Consequently, the following recommendations are made:

1. An actual solid-waste rail-haul demonstration project—to test full scale the promise of an immediate solution to a growing urban problem; and
2. A feasibility study of recycling as an integral part of solid-waste rail-haul disposal systems—to pursue a highly encouraging approach to the ultimate goal of progressive resource management.

CHAPTER 1

INTRODUCTION

Solid waste is the residue of production and consumption—a by-product of air-and water-pollution control—the litter that people promiscuously discard on the countryside—the "unusable" overburden of mining operations—and the inedible remainder of agricultural production.[1] The total U. S. solid-waste burden, including agricultural, mineral, and ash from fossil fuels, has been estimated at more than 3½ billion tons a year. Household and commercial refuse collected in urban areas constitutes only about one-tenth of the 3½ billion tons of solid waste generated nationally, yet its management requires the most challenging and continuous effort. It is the visible, heterogeneous waste generated where people live, and it poses a real and immediate threat to public health, welfare, and safety if not properly and promptly removed.

The cost of the collection and disposal of urban solid wastes varies widely depending upon variables such as extent and frequency of service, prevailing wage scales, system management and cost accounting techniques, types and quantities of materials accepted, climate, and local physical conditions. Reported collection and disposal costs in urban areas range from less than $10 to more than $30 a ton (1970 dollars), with collection ranging up to 80 percent of the total. The disposal portion also varies widely—75 cents to $8 a ton—according to the method used, but it must be considered with total costs since length of haul to the disposal facility or site influences collection costs.

The solid waste problem is especially acute in the densely settled urban areas. Incineration and landfilling are the principal methods of disposal in urban areas. Incineration basically reduces the waste bulk before final disposal on land. Although increased efforts to salvage and recycle solid wastes promise to reduce the bulk even further, land still will be required for disposal of residues. And in densely settled urban areas, land is not only in short supply, it is also in strong demand for uses more attractive or productive than solid-waste disposal. In competing for the decreasing amounts of land still available, solid-waste disposal is often the loser.

As wastes are transported increasing distances for land disposal, the key factors become processing to reduce bulk prior to transport, and mode of transportation. The problem traditionally has been reduced to two alternatives: transfer and haul of all wastes to sanitary landfills, or incineration to reduce bulk before haul to a land disposal site.

Experience has shown that where suitable sites are available within economic hauling distance, it is less expensive to use the landfill method. The key economic control is the cost of transport, a factor of both distance to the disposal site and the pattern of local waste generation, i.e., inputs from government jurisdictions and the private-sector.

Generally, the lower the unit worth of the shipment, the greater the total weight required to be shipped to obtain economy of operation; as solid wastes have a negative value, the size of the shipment is very important. For that reason, large core cities and their dependent regions are logical input points for solid waste shipment; and railroads offering a high tonnage, long distance, and ubiquitous means of transportation, are the logical carriers.

The feasibility of rail-haul of urban solid wastes was determined by providing seven objectives of the study:

1. to determine the techno-economics of rail-haul;
2. to ascertain the implications to present collection and disposal practices;
3. to identify the required transfer operations and facilities;
4. to evaluate the potential usefulness of industrial material handling experience;
5. to develop and, if necessary, carry out demonstration projects of rail-haul concepts;
6. to evaluate the practicability, efficiency, and safety of the equipment and techniques; and
7. to evaluate the environmental impact.

THE STUDY APPROACH

The study approach was determined in two steps: first, selection of the rail-haul system to be investigated; second, development of research methodology.

Major Rail-Haul/Disposal System Alternatives

Three basic rail-haul/waste disposal systems were considered: rail-haul/sanitary landfill, rail-haul/incineration, and rail-haul/composting. These plus two variations of such systems are given in Table 1, Major Alternatives for Rail-Haul in Solid Waste Disposal Systems. Local collection is common

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[1] Resource Recovery Act of 1970, Report of the Committee on Public Works, United States Senate, July 23, 1970.

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to each; therefore, a rail-haul system, to be immediately applicable, must be complementary to present collection technology and practice. The remaining elements of the systems include various combinations of transfer stations, rail-haul incineration, sanitary landfilling, and composting. Since all systems involve the sanitary landfill to some extent, incineration and composting are regarded as partial rather than complete methods of disposal.

Rail transport may take place before or after a given waste processing operation. If economically feasible, large incinerators, for example, could be built in the countryside where buffer areas might be more easily acquired.

Note that the transportation and disposal operations are not identical for each system. Incineration, for example, requires the transfer, utilization, or disposal of incinerator residues, while composting involves the handling of both the compost and the non-compostible material. Sanitary landfilling is suitable for the greatest variety of solid wastes and entails no subsequent handling. The sequence of transport and disposal methods determines quantities of material to be shipped. Sanitary landfilling involves shipment of all wastes, while incineration before transport reduced the amount to be shipped. The tonnage transported is identical, of course, for all systems in which processing follows the rail-haul.

Finally, the costs of owning and operating the various segments of the five disposal systems vary. Programmed operating costs of incinerators under construction in 1969 and equipped to meet stringent air pollution control requirements reportedly ranged up to $8 per ton of 24-hour-rated capacity. Operational costs of present plants excluding fixed costs vary widely; for example, 1969 costs of operation of four incinerators in the City of Cincinnati averaged $3.58 per ton of refuse handled and in that same year, operation of a 40-year-old

TABLE 1

MAJOR ALTERNATIVES FOR RAIL-HAUL IN SOLID WASTE DISPOSAL SYSTEMS

Overall System Number	Position and Number of Major System Building Blocks[1]				
	(a)	(b)	(c)	(d)	(e)
I	Local Collection	Transfer Station	Rail Haul	Sanitary Landfill Disposal	
II	Local Collection	Incineration	Transfer Station	Rail Haul	Sanitary Landfill Disposal
III	Local Collection	Transfer Station	Rail Haul	Incineration	Sanitary Landfill Disposal
IV	Local Collection	Composting	Transfer Station	Rail Haul	Sanitary landfill Disposal
V	Local Collection	Transfer Station	Rail Haul	Composting	Transport and Sanitary Landfill Disposal[2]

[1] Salvage for reuse may be designed into systems at transfer facilities or disposal sites.

[2] Refers to the transport of compost as well as the ultimate disposal of non-compostable waste items.

obsolete plant in the District of Columbia exceeded $9 a ton. Cost data for operating composting plants is quite limited but is estimated to range in the upper quartile of that reported for incinerators. The key disadvantage of composting in the United States is the lack of markets for the end product and consequent failure of almost all such efforts. In contrast, sanitary landfills are operated for as little as 75 cents a ton, though the upper limit can exceed $4 per ton of refuse handled. The total includes costs of land, equipment, depreciation, labor, operation, and contingencies. The wide variations result from differing operating requirements as well as differing sizes of fill. Fills receiving more than 50,000 tons a year have generally been reported as costing from 75 cents to $2 a ton to operate.

Thus, the cost of existing waste processing methods indicated that a combination of rail-haul and sanitary landfill offers the best promise for development of the most economical solid-waste rail-haul disposal system

Methodology

Economic Guideposts. To identify the potential benefits of a solid-waste rail-haul system, a techno-economic feasibility study is required. Feasibility means the capability of being used, carried out, or dealt with successfully. To ascertain feasibility, both exploratory and developmental research may be needed. Economic feasibility concerns the organization of the system; in this case the location and layout of transfer stations and disposal sites, the routes, and the schedule of operations. Economic considerations must be tempered to enhance community benefit and to obtain public support. To be successful, a solid-waste rail-haul system must, of course, be competitively priced.

Rail rates are determined from specific information about the variables: the origin, the destination, the route or routes to be traveled, the type and size of the cars to be used, the volume to be transported, the schedule frequency, and the type of service required. However, it is possible to generalize on rates to indicate the order of magnitude of rail shipment costs.

The ICC does not regulate the cost of shipment of waste goods – those that have no value. Thus there is an opportunity when dealing with railroads to bargain for an advantageous position. The ICC in early 1971, however, proposed to establish jurisdiction over the transportation of wastes destined for recycling. Thus, if recycling were to be accomplished at a central disposal point, shipment of solid wastes may be regulated, an economic factor which must be considered.

The substantial cost difference between small and large volume shipments results from the different net load capacities of different cars and the use of different cars and the use of different types of trains such as unit trains or regular trains. The cost of small volume shipments, based on data provided by several railroads, is presented in Table 2, Cost Per Ton for Small Volume Shipment by Rail Cars Attached to Regular Trains.

TABLE 2

COST PER TON FOR SMALL VOLUME SHIPMENT BY RAIL CARS ATTACHED TO REGULAR TRAINS

Net Load Capacity per Car (Tons)	Shipping Distance (Miles)		
	50	100	150
50	$5.05	$4.65	$6.30
70	3.70	4.10	4.65
80	3.25	3.75	4.15
100	2.65	3.00	3.45

These figures are based on full carloads, railroad-owned cars and 1968/1969 operating conditions.

In contrast, unit train rates, usually with railroad-owned cars, ranged form $1.50 to $2.00 per ton. Moreover, quotes of 3 to 7 mills per ton per mile have been made in extremely favorable circumstances if such unit loads exceed 8,000 net tons and operate with shipper-owned cars.

Thus, the economics of large volume rail-haul shipments may be attractive for large metropolitan areas where most of the urban solid wastes originate and where the disposal problem is most acute. Rail-haul of solid wastes should be based on shipment tonnages which take advantage of unit-train rate structures. General operating conditions tend to confirm this. In conventional service, cars are moving in trains about 10 percent of the time, or about 2½ hours a day. Moreover, nearly 4 percent of this 10 percent is for cars moving empty, so that an average car is used only 6 percent of the time in revenue service movement. It averages only 52 miles a day; the rest of the time it is standing. A car stands in the customers' yards about 40 percent of the time; the remaining 50 percent of the time it is standing in the rail yards. The railcar in conventional service is wasteful of time and money. The unit-train is a very different story; the 50 percent of rail-yard-time can be cut or even eliminated.

In contrast to conventional trains, unit trains are moving some 500 to 700 miles a day, 50 percent to 90 percent of their total time, with an average near 75 percent. The combination of improved time and load-usage factors of unit trains results in the fixed equipment costs being spread over 10 to 30 times more of the load than in conventional service. This is a very significant and favorable economic factor.

Conceptualization of the Study. The establishment of a suitable solid-waste rail-haul system involves, like the development of all technologies, an evolutionary process. The system was conceived within the framework of developments readily attainable, and concepts requiring a long lead time were avoided. It was recognized as a system containing major building blocks and many interrelated elements.

Major areas of investigation were identified: criteria for system evaluation, composition of the wastes, transfer, public health and environmental control, rail transport, and sanitary landfill operations. The major study areas along with correlated substudy efforts are listed in Table 3, An Outline of Major Areas of Investigation.

Criteria or yardsticks are of key importance for a feasibility study aimed at the development and evaluation of a new system in which cost/performance relationships are decisive. By establishing the characteristics of an ideal system, the criteria provide guidance for the identification of problem areas, the allocation of efforts, and the evaluation of given or potential alternatives.

The investigation of the feasibility of solid-waste rail-haul requires identification of the composition and quantities of solid wastes that the system must handle. Such information is basic to the type and degree of processing that is required for satisfactory input of the materials into the rail-haul system as well as specific system configuration, e.g., type of train service, landfill operations and public health, safety and environmental control requirements.

Salvage was considered an important substudy effort since salvaging a substantial amount of paper and metals content could change drastically the solid waste processing requirements as well as other system demands.

Transfer of wastes from the delivery vehicle to the rail-haul system may be accomplished by:

a. transfer unprocessed, as delivered (materials handling),
b. transfer of compacted or shredding materials (materials processing),
c. combination of "a" and "b."

Materials handling and processing analyses are necessary to determine, for example, the feasibility of achieving maximum payloads per car with a reduction in the transportation costs.

The public health and environmental control aspects of solid-waste rail-haul are influenced by the composition and quality of the materials that go into the system and by any processing the wastes undergo. These aspects, however, should be evaluated for all of the major building blocks of any solid waste management system.

Rail-haul constitutes the major building block for determining the feasibility of a solid-waste rail-haul system. The rail-haul investigation was specifically concerned with:

a. rail car selection;
b. train configurations;
c. an interstate rail-network analysis for several states aimed at determining, for illustrative purposes, the potential location, number, and capacity of disposal sites suitable to serve a large geographical area;
d. an analysis of shipping costs and factors considered in the establishment of rate structures; and
e. evaluation of nonrail modes of long-distance transport for comparative purposes.

Sanitary landfilling as a part of a rail-haul system employs well known and tested procedures for large scale operations. In addition, rail-haul can provide access to active strip mines, opening new disposal opportunities and providing significant benefits through land reclamation. Moreover, the synergistic effects of the integration of strip mine and sanitary landfill operations can lead to reduced costs.

Studies on the disposal aspects had to be cognizant of many system- and nonsystem-related factors. Although the investigations revealed that the acquisition of disposal sites is a major problem, they also indicated that the number of potentially acceptable sites is greatly increased when the rail-haul concept is employed.

In the final analysis, the adoption of a solid-waste rail-haul system is dependent not only upon the techno-economic feasibility of the individual building blocks but also upon political, regulatory, and environmental quality considerations.

TABLE 3

AN OUTLINE OF MAJOR AREAS OF INVESTIGATION

Major Area	Correlated Substudy Efforts[1]
1. Criteria for system evaluation	None
2. Composition and Quantity	Detailed identification of chemical constituents and properties. Evaluation of potential impact and significance of salvage operations.
3. Transfer a) unprocessed solid wastes b) mechanical processing size reduction compaction c) material handling requirements d) transfer station layout	The feasibility and value of chemical processing. The feasibility and value of size reduction (shredding). Exploratory spot testing of processing solid wastes by compaction.
4. Public Health and Environmental Control Factors a. pathogens b. chemical pollution c. vector control (insects and rodents) e. aesthetics f. safety	Identification of basic solid waste public health, nuisance, and other environmental impact factors.
5. Rail Transport a) rail car selection b) train configuration c) network analysis d) rail rates and costs	The comparative economics of nonrail modes of transport for the long distance naul of solid wastes.
6. Sanitary Landfill Operations a. the scale-up of operations b. the disposal implications of processed wastes c. disposal in active strip mines	Evaluation of alternatives for integrating strip mine operations with solid waste disposal.

[1] These substudy efforts were undertaken in order (a) to provide the necessary input information not available from other sources or (b) to provide the needed perspective with regard to the main areas of investigation.

CHAPTER 2

DESIGN AND PROCESSING FOR RAIL-HAUL

A "criterion" is information upon which a judgment may be based. Unlike a standard it carries no connotation of authority other than that of fairness and equity; nor does it imply an ideal condition. When technological data and other information are being compiled to evaluate the potential effectiveness of a solid waste disposal system, without regard for legal authority, the term "criterion" is most applicable.

The criteria for a solid waste disposal system can be identified as follows:

The system should:

1. be capable of handling all solid wastes generated in the community, accommodating
   a. residential, municipal, commercial, and industrial wastes irrespective of composition, moisture content, age, or unit size, and
   b. large and small input loads including sudden surges, seasonal fluctuations, and gradual increases or decreases in the workload;
2. at least meet existing public health and environmental control standards:
   a. function without polluting air, water, or land;
   b. be free from noise, dust, odor, and unsightliness;
   c. provide a hygienic work environment;
   d. be esthetically pleasing to the public;
3. function effectively
   a. in all weather conditions;
   b. without disruption of the whole by damage to a part of the system;
   c. using proven elements and practices; and
   d. with resilience under catastrophic conditions;
4. be capable of serving
   a. small and large communities individually or collectively;
   b. regions, all or part;
5. be economically competitive with other systems in respect to
   a. the total cost, including investment, operations, and maintenance;
   b. compatability with local collection efforts;
   c. adaptability permitting rapid cutback in costs if the load is reduced, regardless of whether the reduction is temporary or permanent;
   d. the attraction it may hold for private enterprise; and
   e. the overall economic impact on a given area;
6. have organizational simplicity, but
   a. offer potential users management and implementation options;
   b. adapt to user needs and not vice versa;
7. have an inherent attractiveness for implementation by being
   a. publicly acceptable;
   b. rapidly adoptable by governmental jurisdictions, commercial collection and disposal firms, and industries which provide disposal facilities themselves;
   c. amenable to product, process, or methods evolution;
   d. promising in terms of side benefits, such as salvage or land reclamation.

The degree to which any existing or proposed solid waste disposal system meets these criteria can be taken as a measure of its relative merit. It is, of course, recognized that no solid waste disposal system exists which meets all of these criteria to the fullest extent possible. Thus, any system evaluation, selection, or development must emphasize optimization.

COMPOSITION AND QUANTITY

Solid waste is a heterogeneous mixture of materials containing a wide variety of chemical compounds and elements. Solid wastes have a liquid content including the water in food wastes and that resulting from its exposure to rainfall. Other liquids, usually in containers, such as waste oil are also found in solid wastes. The moisture content of solid wastes varies appreciably.

The major sources of solid wastes collected in urban areas may be categorized as residential, commercial, industrial, institutional, and municipal, and those produced by demolition and construction. Agricultural and mining wastes ordinarily are not handled in urban systems.

About 3,000 pounds of solid wastes per capita are collected in United States urban areas each year (Table 4). It is well known that additional quantities of solid wastes are generated in urban areas but are not accounted for in the quantities reported as "collected." This is the result of many factors

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TABLE 4

SOLID WASTES COLLECTED IN URBAN AREAS IN THE UNITED STATES

Class of Refuse	Population Reporting (1000)	Pounds/ Capita/ Year
Combined household and commercial	34,213	1,570
Industrial	25,213	690
Institutional	17,337	60
Demolition and construction	21,716	260
Street and alley cleanings	32,705	90
Tree and landscaping	23,405	70
Park and beach	17,006	50
Catch basin	20,042	10
Sewage treatment plant solids	19,100	180
Total Solid Wastes Collected		2,980

Source 1968 National Survey of Community Solid Wastes Practices U. S. Public Health Service.

Because reports on all categories were not obtainable from every community the population base for each figure is shown. Total does not include agricultural and mineral wastes.

TABLE 5

EXPECTED RANGES OF SOLID WASTES COMPOSITION

Class of Refuse	Percentage Composition (Dry Weight Basis)	
	Range	Nominal
Paper	37-60	55
Newsprint	7-15	12
Cardboard	4-18	11
Other	26-37	32
Metalics	7-10	9
Ferrous	6- 8	7.5
Nonferrous	1- 2	1.5
Food	12-18	14
Yard	4-10	5
Wood	1- 4	4
Glass	6-12	9
Plastic	1- 3	1
Miscellaneous	5	3
		100

Note: Moisture Content Range 20%-40%
Nominal 30%

Source: National Survey of Community Solid Wastes Practices.

including simple lack of records, periodic removal of salvageable materials from the waste stream for recycling or reclamation, and on-site disposal. Millions of household, commercial, and institutional food waste grinders are used to dispose of garbage through the community sewer system; many institutions, industries, and multiple dwelling complexes incinerate combustibles and maintain land disposal areas on their property. Large quantities of refuse are disposed of at unauthorized sites. The variations among local systems and among types of refuse underscore the importance of thorough investigation of local and regional input factors in the design and operation of community solid waste management systems.

Composition According to Origin

Residential wastes contain a great variety of manufactured and natural products. Most of the items, such as cans, bottles, and paper products, are relatively small; oversized wastes, such as furniture, refrigerators, and large appliances, are usually handled by special collections. Geography, climate, and season of the year have a large impact on refuse content, i.e., yard wastes such as grass clippings may be minimal in a temperate climate in January, but may make up ten percent of the refuse in the grass growing period. The composition range of so-called mixed refuse from a community[2] (but not including heavy industrial, catch basin, sewage treatment solids, or demolition and construction refuse) is shown in Table 5.

These ranges are subject to sharp variation. For example, an individual truckload of refuse may contain up to 100 percent of a waste product such as paper, palm fronds, or spoiled and discarded food. Commercial refuse is generated mainly in offices, stores, theaters, markets, hotels, and restaurants and usually contains large amounts of packaging materials and food discards. Institutional refuse is similar to residential and commercial refuse but also contains specialized wastes; for example, hospitals and clinics generate chemical and pathological wastes which require special attention. Solid wastes from industry include a wide variety of organic and inorganic refuse (Table 6). The refuse varies from large heavy packing crates and chemical sludges to cafeteria food wastes and office discards. Much of industrial refuse is related to a particular process and product manufactured. The term municipal solid wastes is used as an umbrella for a wide variety of community refuse which is produced largely by municipal operations. This includes street and alley cleanings, park and beach refuse, catch basin cleanings, sewage

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[2] "Processing and Recovery of Municipal Solid Waste," R. F. Testin and N. L. Drobny Journal of the Sanitary Engineering Division, ASCE, 96:3:June, 1970.

TABLE 6

INDUSTRIAL WASTES

Industry	Composition (Process Wastes)
Paper	Sawdust, dust from rag stock, lime sludge, black carbon residue, paper rejects.
Fruit and Vegetable	Scraps of fruit and vegetables, seeds, cobs, oils, processing chemicals.
Meat and Poultry	Flesh, entrails, hair, feathers, fat, bones, blood, grease.
Dairy	Butterfat, milk solids, ash, acids, discarded milk and cheese.
Glass and Ceramics	Broken ceramics, some glass, sludges, dusts, chemicals, abrasives.
Metallurgical	Emulsified cleaners, machine oils, oily sludge, borings and trimmings, toxic chemicals.
Iron Foundries	Cupola slag, iron dust.
Plastics	Scraps from molding and extrusion, rejects, chemicals.
Textiles	Textile fibers (plastic and natural), rags, processing chemicals, detergents.
Construction (including remodeling and demolition)	Sand, cement, brick, masonry, metal, ceramics, plastics, and glass.
Chemical	Organic and inorganic chemicals and rejects of synthetic products such as fibers, rubbers, pigments; can contain toxic, explosive and radioactive wastes.
Lumber and Furniture	Sawdust, wood chips, abrasives, oily rags, upholstery materials, paints, varnishes, scraps of wood, plastics, and textiles.

treatment plant solids, and tree and landscaping debris from public property. Tree and landscaping debris from private property is usually handled by private contractors, although it may be disposed of at municipal facilities. Abandoned automobiles also may be a class of municipal refuse if the market is such that scrap processors or parts dealers will not receive them.

Demolition and construction refuse results from urban renewal programs, normal replacement of urban buildings, and new construction. It consists of noncombustibles, such as brick, concrete, ceramics, and steel; and combustibles, such as lumber. Salvage influences the overall amount of material for disposal (for example, reclamation of old brick) as do air pollution regulations prohibiting on-site burning of combustible debris. Demolition refuse is relatively incompressible. Landfilling is the only practicable way to dispose of the rubble component of this waste material.

Trends in solid waste composition are evident. The amount of food wastes in household refuse is diminishing while the amount of paper products is increasing. The per capita amounts of paper consumed in the United States have risen more than twice as fast (by weight) as the population increase. This increase in tonnage has been registered in spite of the fact that one ton of paper pulp now yields as much as 50 percent more paper products than it once did. The same trend is evidenced in metal can production. The 65 billion cans produced in 1969 were manufactured from the same steel tonnage as was used to produce 50 billion cans in 1965. Volume and compressibility emerge as key factors in the materials handling requirements of urban solid wastes.

Chemical and Physical Properties

Development of a rail-haul system requires information about the physical, chemical, and biological properties of the solid wastes to be handled. A list of manufactured and natural products found in solid wastes was developed and is presented in Tables 36-52, Appendix A. The tables also contain information on physical structure of constituents, such as paper, plastics, and rubber. These are particularly important in understanding the processing system element.

Table 38 contains information about the composition of paper products, which constitute a major part of solid wastes. Tables 41 and 42 identify chemical constituents, high water content, and the bacterial products of food and plant wastes, which are a source of nutrients for microorganisms. Tables

43-46 give the chemical and physical structure of plastics, textiles, leather, and rubber, all of which are composed of long-chain molecules which have elastic properties. Tables 48-51 provide data on paints and varnishes, insecticides and cosmetics, and construction wastes.

Quantities

The quantity of solid wastes which may be handled in a rail-haul system depends on the size of the area served, the type and amount of solid wastes generated within that area, and system utilization factors. For example, if use is permissive, much less material may be expected to be introduced into the system than if it were compulsory. The potential quantity of solid wastes from a given service area may be estimated for illustrative purposes by computing the product of population and per capita production. The potential service area for a solid-waste rail-haul system can be gauged by the number of people living in the relatively densely settled metropolitan areas which, of course, are served by railroads. The potential service area of one large railroad system, the Penn Central Railroad, is shown in Table 7. Based on an annual per capita quantity of one and a half tons, if the solid wastes from these metropolitan areas were handled by one solid-waste rail-haul system, the annual tonnage would amount to more than 100 million. This is almost two million tons a week — or 400,000 tons a day calculated at 260 working days a year. The data at least indicate the order of magnitude of the solid waste quantities which might be handled by a rail-haul system. The example is based on present discard and collection practices, and assumes that everything collected goes into the rail-haul system. For the purpose of systems design, critical capacity loads are not yearly averages but high weekly averages, with due consideration given such factors as seasonal variations and collection frequency. The Monday collection of household refuse may deliver twice the amount of refuse to the disposal facility that the Thursday collection will deliver if twice weekly collection service is offered. On the other hand, daily collection quantities tend to vary little and reflect only seasonal differences.

Relevance of Waste Characteristics

The relative importance of composition, quantities, and unit sizes of solid wastes can best be understood by evaluating their effect on rail-haul

TABLE 7

State Population Living in Standard Metropolitan Statistical Areas Served by a Large Railroad System

		POPULATION LIVING IN SMSA			
		Served/Penn Central		Not Served/Penn Central	
State	State (Total) Population	Population	% of State Total	Population	% of State Total
Illinois	10,775,300	7,682,300	71.3	770 900	7.1
Indiana	4,958,400	3,400,900	68.6		
Kentucky	3,164,500	796,300	25.2	368,300	11.6
Maryland – D.C.	6,241,100	4,804,900	77.0		
Massachusetts	5,424,500	4,350,000	83.5	734,000	13.5
Michigan	8,392,100	6,190,600	73.8	588,800	7.0
Missouri	4,516,000	2,282,700	50.5	1,572,400	34.8
New Jersey	6,910,700	3,511,700	50.8	2,045,100	29.6
New York	18,101,700	16,224,800	89.6	304,500	1.7
Ohio	10,537,200	8,747,300	83.0	82,600	0.8
Pennsylvania	11,711,400	9,922,800	84.8	746,300	6.4
West Virginia	1,771,600	514,300	29.0	211,900	12.0
	92,504,500	68,619,600	74.2	7,424,800	8.0

Source: U.S. Bureau of the Census, Sales Management Magazine, Railroad Guide system elements such as processing, public health, transport, and landfilling. A processing operation is based on knowledge of the physical and chemical composition of the material and the volume to be processed. For chemical dissolution processing, for example, the solubility of waste components must be known. The major constituent of paper products – the major portion of residential wastes – is α-cellulose. This constituent is insoluble in water and cold alkalies and only partially soluble in dilute acids. Thus, other solvents have to be used if the major part of paper is to be dissolved. Materials such as paper, plastics, and rubber are made up of long-chain molecules which exhibit fiber structures and elastic properties. Size reduction – physical processing of these materials – should be accomplished by a tearing action along the fiber and by cutting the fibers. In compaction, the fiber structure of such materials has to be considered since bent fibers tend to spring back. Physical characteristics of solid wastes, i.e., size and weight relationships, govern the design of material handling operations, process feeding devices, and the general process and system layout.

Composition, along with concentration of specific waste constituents, affect public health and the environmental control measures. For example, wastes which contain a high proportion of foods provide an excellent medium for bacterial survival and multiplication. Furthermore, bacterial degradation products, especially from animal proteins, often produce offensive smelling vapors and gases. Control measures for wastes containing putrescible organics should provide for odor control as well as fly and rat control. Large volumes affect not only the physical elements of transport and landfill but also the concentration of the waste constituents in a restricted space. Depending on the nature of the constituents, they might require special provisions in both transport and landfills.

RECYCLE AND REUSE

Salvaging from the solid waste stream for recycle and reuse directly affects the composition and quantity of the refuse. Salvage may take place before or after the wastes enter the disposal system, posing two basic questions: 1. How is the rail-haul of solid wastes affected by salvage, and 2. how does a rail-haul system affect the prospects for salvage?

Technical Considerations

Technology of a salvage process must be geared to the composition of the refuse and end-product requirements. Ideally, a high concentration of desirable substances and a low concentration of undesirable constituents should be present in the source material. The heterogeneous nature of solid wastes and the composite nature of individual items contained in solid wastes tends to dictate multi-step processing for recovery.

Separation of certain kinds of wastes, such as paper, metals, and glass, before collection would greatly simplify the difficult and costly task of subsequent separation and the necessity of additional treatment to remove harmful contaminants. However, this would probably increase collection costs. Removing traces of paints, oils, and acids is costly. The well-established trend of household collection service is to collect mixed refuse. However, much commercial and industrial refuse is large quantities of single items – paperboard from packaging, or metal trimmings from a manufacturing process, for example. Considerable quantities of such material are already recovered for recycling at the source of generation.

Recovery of materials from waste mixtures can be accomplished both by physical and chemical means. The methods differ depending upon whether separation into groups or extraction of specific items or individual chemical components is attempted. In all cases the separation is accomplished by utilizing inherent differences in the properties of the materials. Separation into broad groups usually requires methods based on gross differences in properties. More specific material salvaging techniques must be utilized for the extraction of specific items such as individual chemical constituents. Physical methods used in industry for the gross separation of materials include those based on mechanical, magnetic, electrical, optical, and surface properties. Screening and classification (particle separation), ballistic separation (based on gravity), and magnetic separation (ferromagnetism) have been applied to the separation of solid wastes. Chemical processes have also been used in the solid waste field. Incineration can be classified as a chemical, volume reduction, gross separation method. A nearly limitless number of steps would be required for the separation of all chemical constituents present in wastes. The technical methods of separating even traces of such constituents are available but the extraction of all constituents has not been considered practicable or economical. Technical processes based upon the extraction or conversion of a single constituent, if the constituent is not present in high concentrations or has no use or economic value, are not considered solutions to the present problem. Recovery and conversion processes, composed of a minimum number of steps and capable of extracting or converting the maximum quantity or a large number of constituents simultaneously into useful products, appear to offer the most potential. The utilization of the mixture without processing or after shredding and compaction as filling material in land recovery is such a process.

Economic Considerations

The economic aspects of salvaging or resource recycling are basically the cost of the process (or processes) and its logistics, and the disposition of the salvaged material. The lower the salvage process cost the greater, in principle, the share of the total "sales price" which can be allocated to logistics i.e., the material handling, storage, and transport of the items involved. The factor of logistics appears to represent the more difficult problem for salvaging residential wastes. Many variables have to be considered and many alternative system configurations are possible. The major factors influencing logistics include:

a. the objective or objectives of the salvage operation, e.g., whether to salvage one, more than one, or all of the waste materials;
b. the type and economics of scale required for the salvage operations to meet the objectives, e.g., whether large or small plants are necessary, whether physical separation by hand or mechanical means is sufficient, or whether additional processes are needed; and
c. the location of the salvage operations with respect to source of the wastes and disposal of residues.

The logistics of collection, accumulation, and distribution can be relatively simple or quite complex. If, for example, separation by hand at the home is the *only* requirement, then separate or compartmentalized storage and collection of one or more items is needed in the implementation. The logistics are simplified if only one item is salvaged and the remainder of the wastes are disposed of as usual. Generally, the complexity increases with the number of items salvaged and the diversity and quality requirements of the market outlets for the recoverable items.

Processing solid wastes for resource recovery whether done within or without a rail-haul system, could have significant effects on the system. Reduced quantities could appreciably reduce overall costs, but a reduced quantity could also increase unit shipping costs. Within a rail-haul system, salvaging could be performed in or close to a transfer station or at the sanitary landfill site.

Use of the rail-haul concept can concentrate large amounts of solid wastes into one or more locations. This provides a favorable base for salvage processes which require a large throughput. It also may serve as a focal point for new plants producing new products made from solid wastes or plants which use new, solid waste oriented manufacturing processes. In this way, solid waste salvaging logistics may be simplified since the number and quantities of materials that need to be transported are reduced.

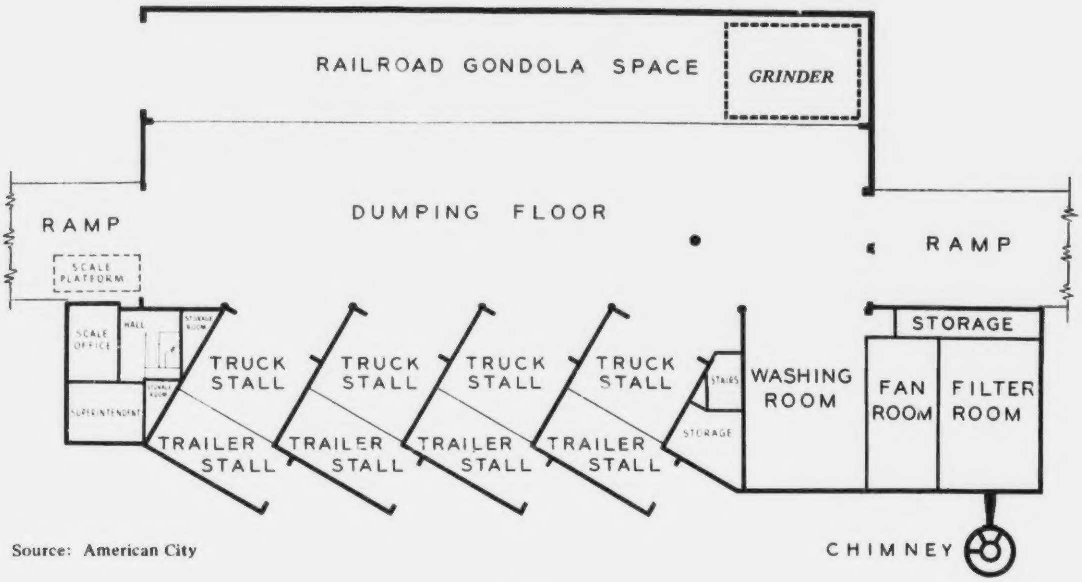
The interface of the community collection and rail transport portions of a solid waste management system requires a materials handling-processing facility of some type. The design of this facility could well incorporate elements of materials separation and reshipment within the flow pattern of the disposal system. It can be concluded then that evaluation of such facilities for use as processing points for separation of marketable items and components of the urban solid wastes burden may be considered a valid and desirable consideration in the evaluation of the feasibility of a rail-haul system.

PROCESSING AND TRANSFER FACILITIES

The function of a processing and transfer facility is to receive refuse from vehicles which are used to collect solid wastes from generating sources, to provide for pre long-haul processing (such as salvage and densification), and to transfer residues to equipment better suited to long hauls, such as large trailer trucks or rail cars. Many communities presently use collection-transfer long-haul systems. One such installation began operation in 1950 in Washington, D. C., (Fig.1). The facility, which is still in limited use, transfers street and alley sweeping, ashes, and miscellaneous noncombustibles and incinerator residue to gondola cars for transport to a District landfill. The garbage is ground for discharge into a trunk sewer or loaded into trailer trucks.

Nuisance-free operation was achieved largely through the installation of a fiber glass and activated-carbon dust and odor control system. When it was first placed in operation about 1 million cubic yards, or 25 percent of the total production of the District of Columbia, was processed through the facility (3 million cubic yards of combustibles were disposed of annually at the District's incinerators and a landfill).

The basic concepts of processing and transfer facilities have been developed and applied over a relatively long period. There remains, however, the


RAILROAD GONDOLA SPACE
GRINDER
DUMPING FLOOR
RAMP
SCALE PLATFORM
SCALE OFFICE
HALL
STORAGE ROOM
SUPERINTENDENT
TRUCK STALL
TRUCK STALL
TRUCK STALL
TRUCK STALL
TRAILER STALL
TRAILER STALL
TRAILER STALL
TRAILER STALL
STAIRS
STORAGE
WASHING ROOM
RAMP
STORAGE
FAN ROOM
FILTER ROOM
CHIMNEY

Source: American City

FIGURE 1
DISTRICT OF COLUMBIA TRANSFER STATION

need to adapt this experience to the use of long distance rail-haul systems. Figure 2a is a schematic of the basic elements of the transfer facility development process; Figure 2b details the elements of the interface of local collections with the transfer facility development process.

Beginning with the interface with local collection, the transfer station system is developed through the establishment or location of facilities and methods of transfer from the local collection vehicle as governed by community ordinances and regulations. The transfer stations are composed of stationary and mobile equipment and facilities compatible to the total system Specific considerations include:

a. the types and amounts of solid wastes generated in the various sections of a community, i.e., industrial parks, residential areas, and commercial centers;
b. future community development and solid waste generation patterns;
c. the structure of the public and private collection effort, i.e., type and capacity of vehicles, collection routes, and collection schedules; and
d. the identification of desirable transfer station service areas and functions.

Interface with Local Collection

The waste receiving operations are the physical interface of a transfer station with the local collection vehicles. The design of these operations is largely determined by the operating capacity of the transfer station and the net load of the collection vehicle. For example, if the average net load per truck is 2.5 tons, a transfer station rated at 1,000 tons a day should theoretically receive 400 trucks a day. However, the trucks will not arrive at the transfer station at uniform time intervals because of existing practices and regulations of the working time. Sometimes as many as 30 to 50 percent of the total number might arrive within 1 to 2 hours; thus, a 1,000-ton transfer station would be designed to receive up to 100 collection units/hour during the daily peak traffic period.

Operating costs of the collection fleet may make it uneconomical to concentrate the unloading at one transfer station for such a large number of collection vehicles. Thus, in suburban or low density areas it may be necessary to use one or more sub-stations for the transfer operation.

Many transfer station layout concepts can be developed. The factors affecting layout include: the

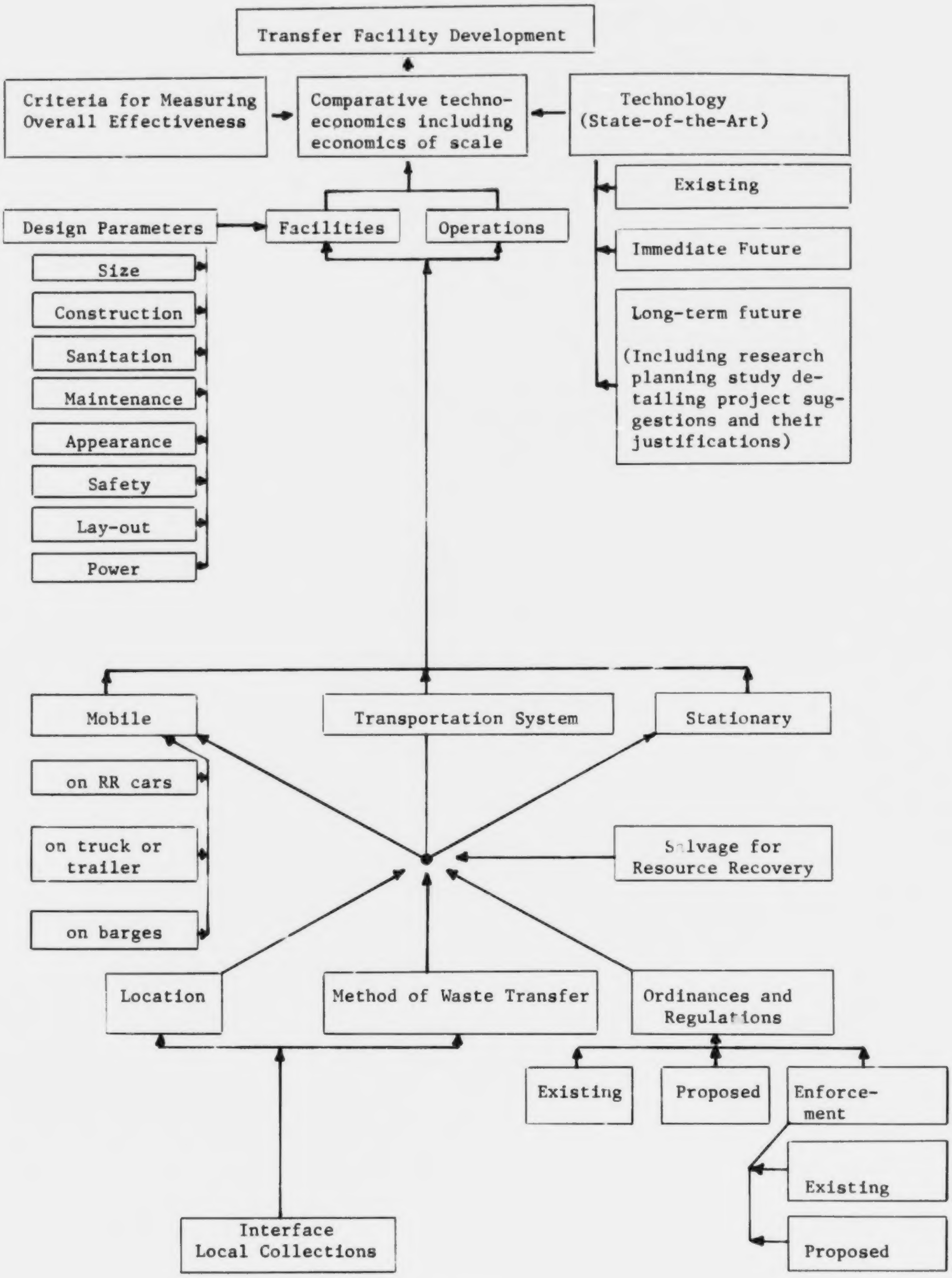

Transfer Facility Development
Criteria for Measuring Overall Effectiveness
Comparative techno-economics including economics of scale
Technology (State-of-the-Art)
Existing
Immediate Future
Long-term future
(Including research planning study detailing project suggestions and their justifications)
Design Parameters
Facilities
Operations
Size
Construction
Sanitation
Maintenance
Appearance
Safety
Lay-out
Power
Mobile
Transportation System
Stationary
on RR cars
on truck or trailer
on barges
Salvage for Resource Recovery
Location
Method of Waste Transfer
Ordinances and Regulations
Existing
Proposed
Enforcement
Existing
Proposed
Interface Local Collections

FIGURE 2a
TRANSFER FACILITY DEVELOPMENT

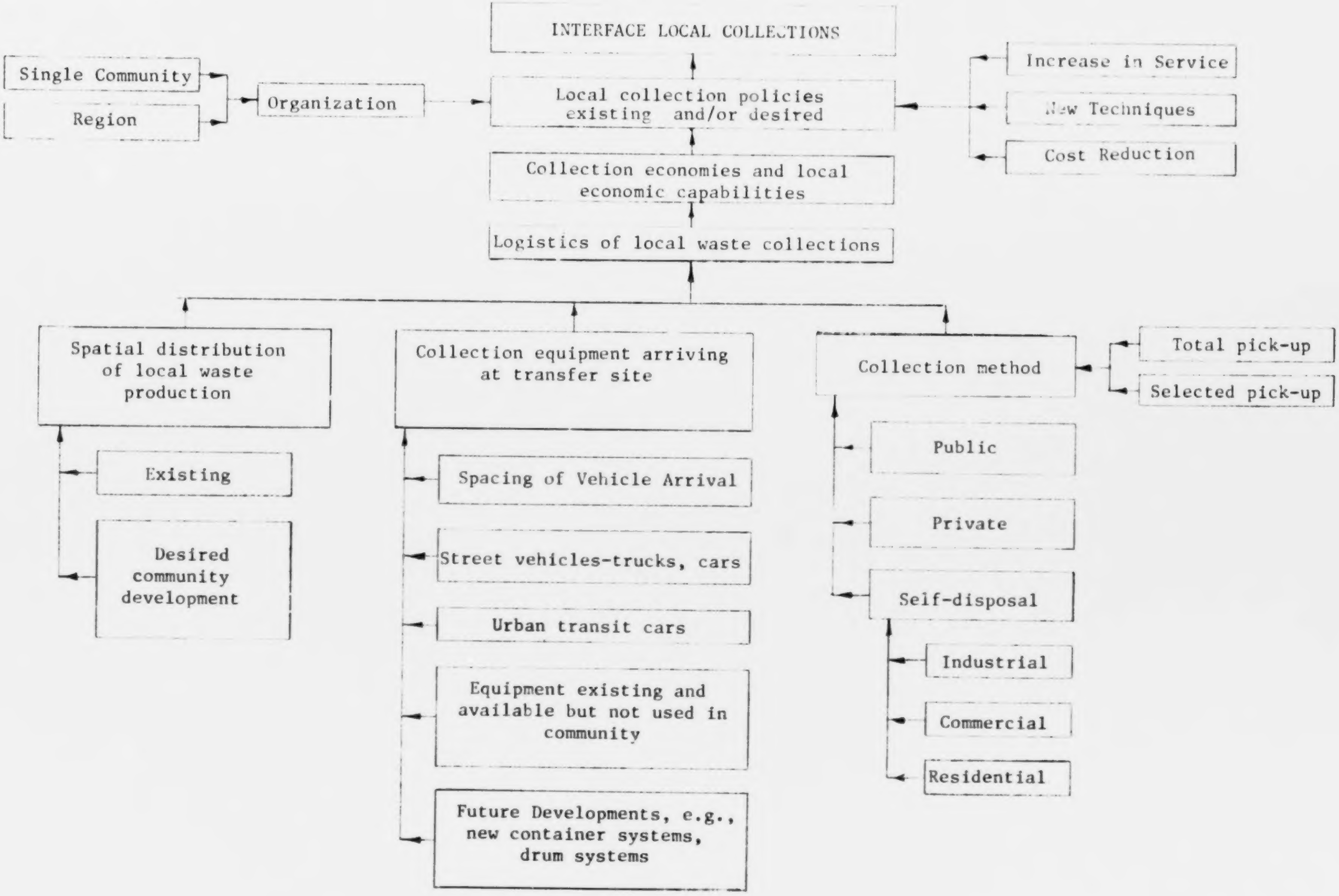

INTERFACE LOCAL COLLECTIONS
Single Community
Region
Organization
Local collection policies existing and/or desired
Increase in Service
New Techniques
Cost Reduction
Collection economies and local economic capabilities
Logistics of local waste collections
Spatial distribution of local waste production
Existing
Desired community development
Collection equipment arriving at transfer site
Spacing of Vehicle Arrival
Street vehicles-trucks, cars
Urban transit cars
Equipment existing and available but not used in community
Future Developments, e.g., new container systems, drum systems
Collection method
Total pick-up
Selected pick-up
Public
Private
Self-disposal
Industrial
Commercial
Residential

FIGURE 2b
INTERFACE LOCAL COLLECTIONS

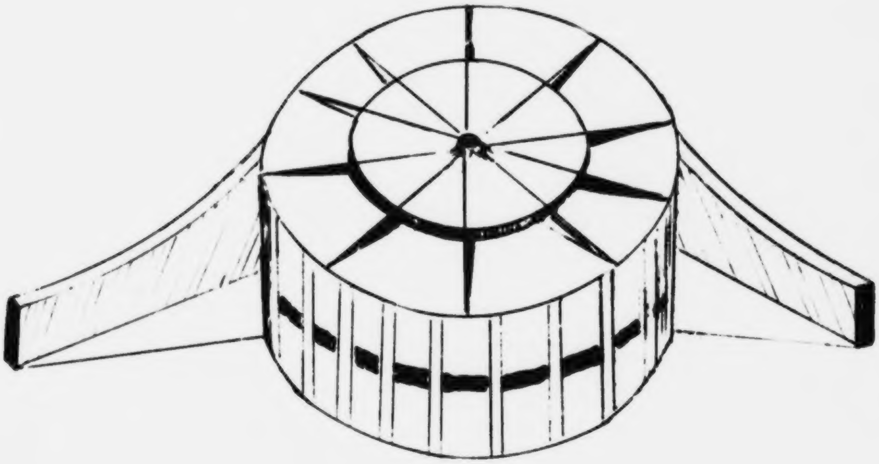


FIGURE 3a

CONCEPT OF A CIRCULAR TRANSFER STATION

design and operation of collection trucks, the collection logistics and the unloading of wastes, the in-station process and material handling requirements, and the loading of the rail cars. The many alternatives in transfer station layout concepts include:

1. a circular transfer station;
2. a design in which the railroad cars pass through the center of the station to permit the loading of the cars from two sides, utilizing gravity loading principles;
3. a small, one-operator transfer station in which materials are moved by an inclined, oscillating conveyor;
4. an "H" pattern station in which the layout resembles the capital letter "H";
5. a compressed "T" layout–with a shortened center but elongated crossbar;
6. a layout adapted to operations in incinerators to be converted for this purpose;
7. a conventional design–similar to existing transfer stations.

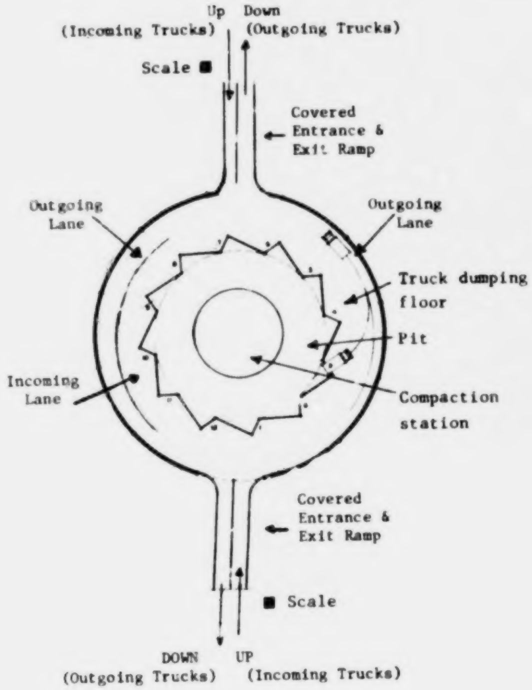
Most layouts can be developed to suit site configurations. An artist's concept of a circular transfer station is shown in Figure 3a. Collection truck width dictates a minimum of 12 dumping stalls. Figure 3b is a plan and cross section view of a proposed facility. Other concepts are more adaptable to lesser capacities.

The compressed T is shown in Figure 4 and the herringbone pattern in Figure 5. Figure 6 shows the actual herringbone layout of the 2,000-ton-per-day San Francisco transfer station dedicated in 1970. This was designed for long distance truck haul, but it has an ultimate capacity of 5,000 tons a day and is adaptable to rail haul.

Figure 7, Plan View of Direct Dumping Station, is a sketch prepared by Pullman, Incorporated, of a 1000-ton per shift facility.

Assuming a 10-minute flow-through or dumping turnaround time requirement, a 12-stall station has a capacity of 72 vehicles an hour. If the in-station time per vehicle is reduced to 5 minutes, then the station could accommodate 144 vehicles an hour. The turnaround time for the new San Francisco transfer station is reportedly 4 minutes per vehicle.

Potential variations in the number of trucks using the station in a given period of time require truck entrances and exits to be designed accordingly. An arrival of 72 trucks an hour implies that every 50 seconds one truck enters and leaves the station. The arrival of 144 trucks an hour reduces this time span to 25 seconds. Thus, the 12-stall transfer station


Up
(Incoming Trucks)
Down
(Outgoing Trucks)
Scale
Covered Entrance & Exit Ramp
Outgoing Lane
Outgoing Lane
Truck dumping floor
Pit
Incoming Lane
Compaction station
Covered Entrance & Exit Ramp
Scale
DOWN
(Outgoing Trucks)
UP
(Incoming Trucks)

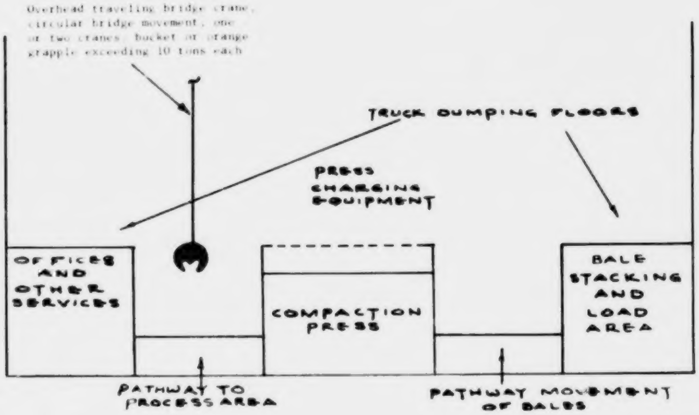

Overhead travelling bridge crane, circular bridge movement, one or two cranes, bucket or orange grapple exceeding 10 tons each
TRUCK DUMPING FLOORS
PRESS CHARGING EQUIPMENT
OFFICES AND OTHER SERVICES
COMPACTION PRESS
BALE STACKING AND LOAD AREA
PATHWAY TO PROCESS AREA
PATHWAY MOVEMENT OF BALES

FIGURE 3b

PLAN VIEW OF TRANSFER STATION BY KAISER ENGINEERS

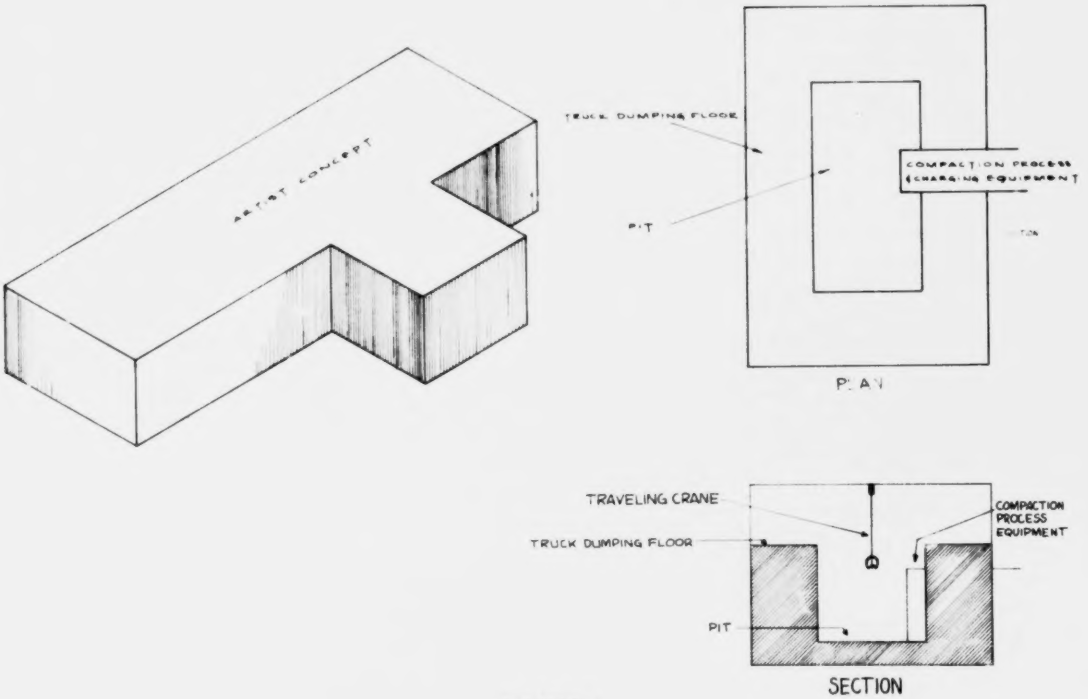

ARTIST CONCEPT
TRUCK DUMPING FLOOR
PIT
COMPACTION PROCESS (CHARGING EQUIPMENT)
PLAN
TRAVELING CRANE
TRUCK DUMPING FLOOR
PIT
COMPACTION PROCESS EQUIPMENT
SECTION

FIGURE 4

CONCEPT OF "COMPRESSED T" TRANSFER STATION

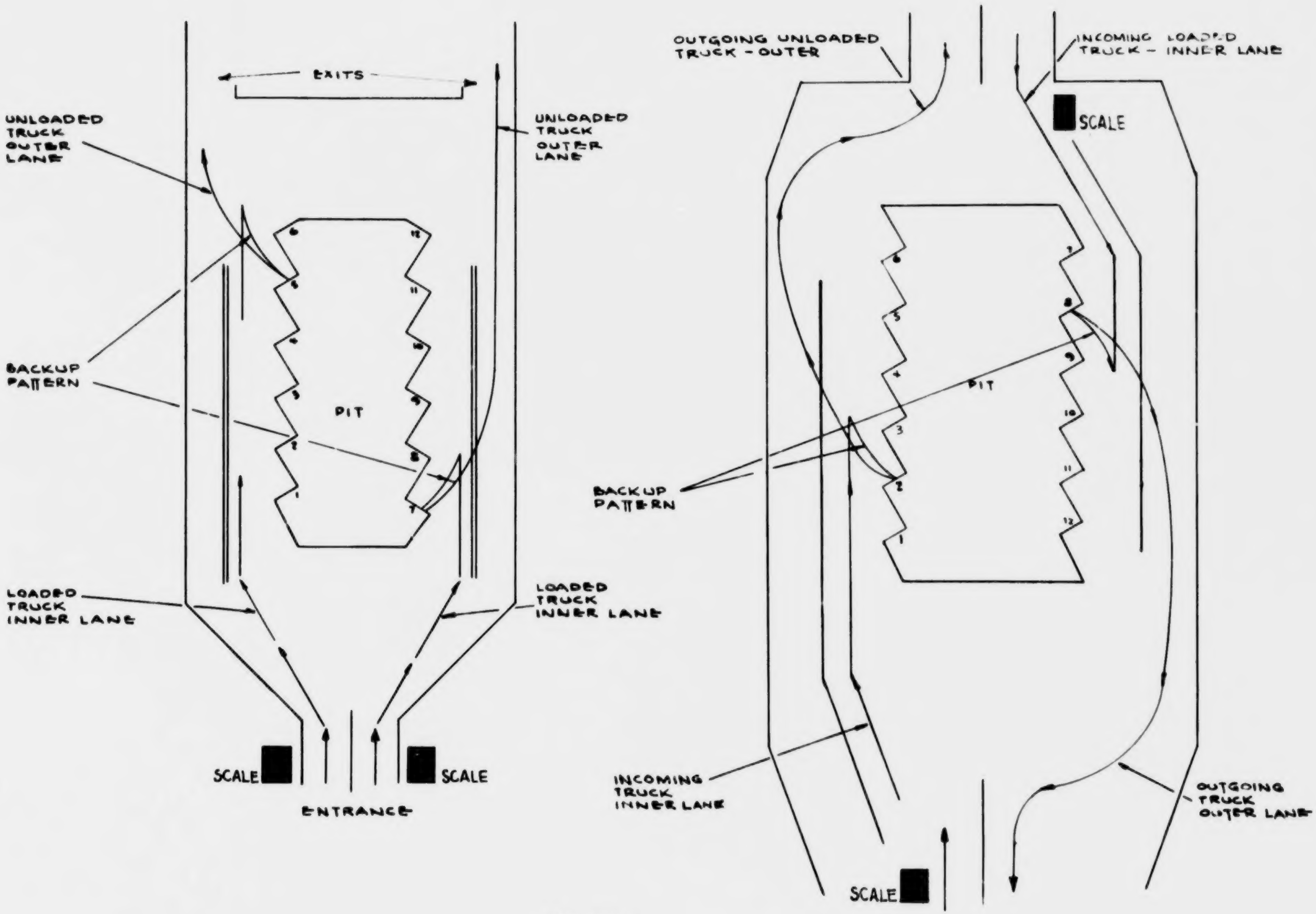
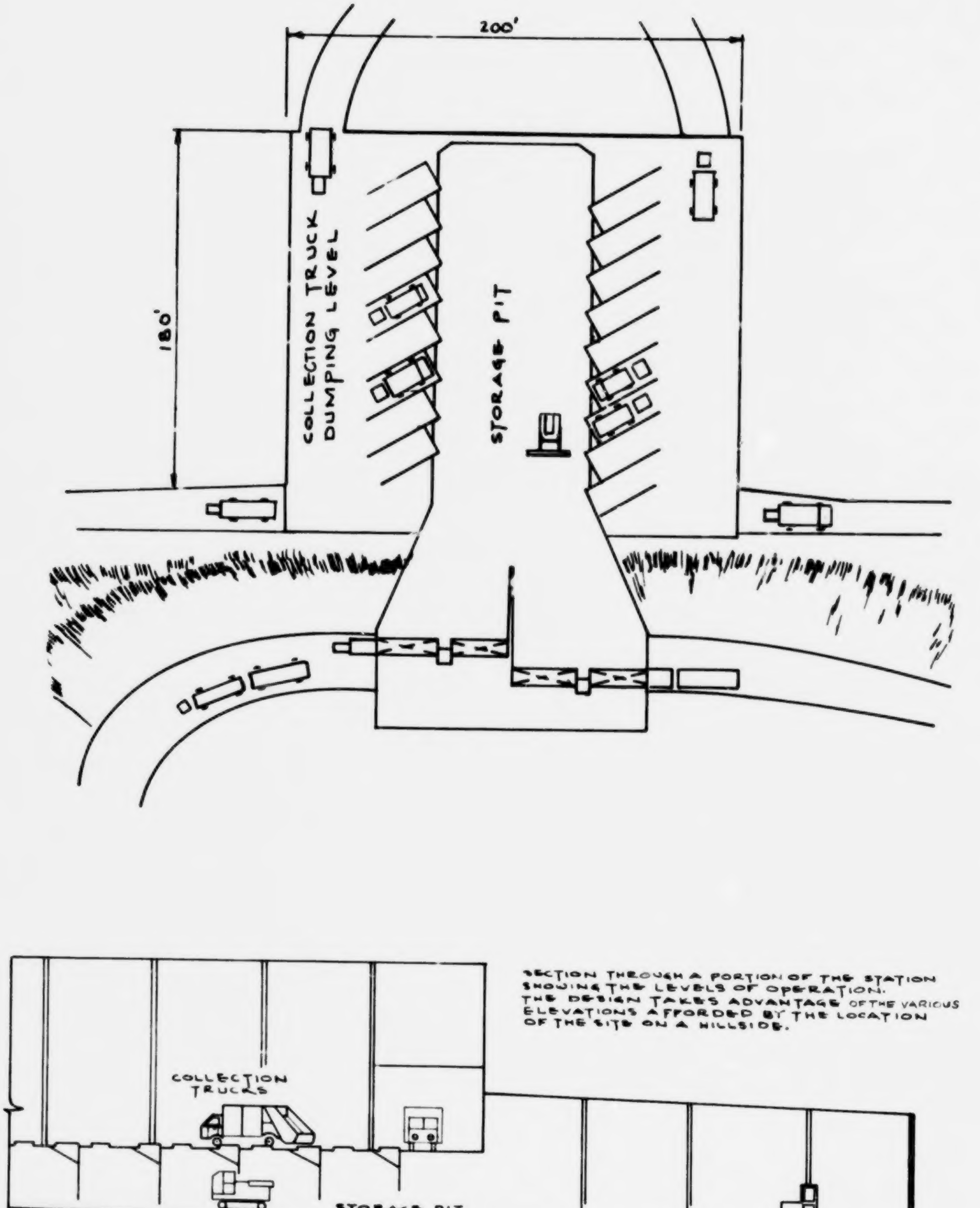

EXITS
UNLOADED TRUCK OUTER LANE
UNLOADED TRUCK OUTER LANE
BACKUP PATTERN
PIT
LOADED TRUCK INNER LANE
LOADED TRUCK INNER LANE
SCALE
SCALE
ENTRANCE
1
2
3
4
5
6
7
8
9
10
11
12
OUTGOING UNLOADED TRUCK - OUTER
INCOMING LOADED TRUCK - INNER LANE
SCALE
PIT
BACKUP PATTERN
INCOMING TRUCK INNER LANE
OUTGOING TRUCK OUTER LANE
SCALE

FIGURE 5

VARIATIONS OF " HERRINGBONE" LAYOUT

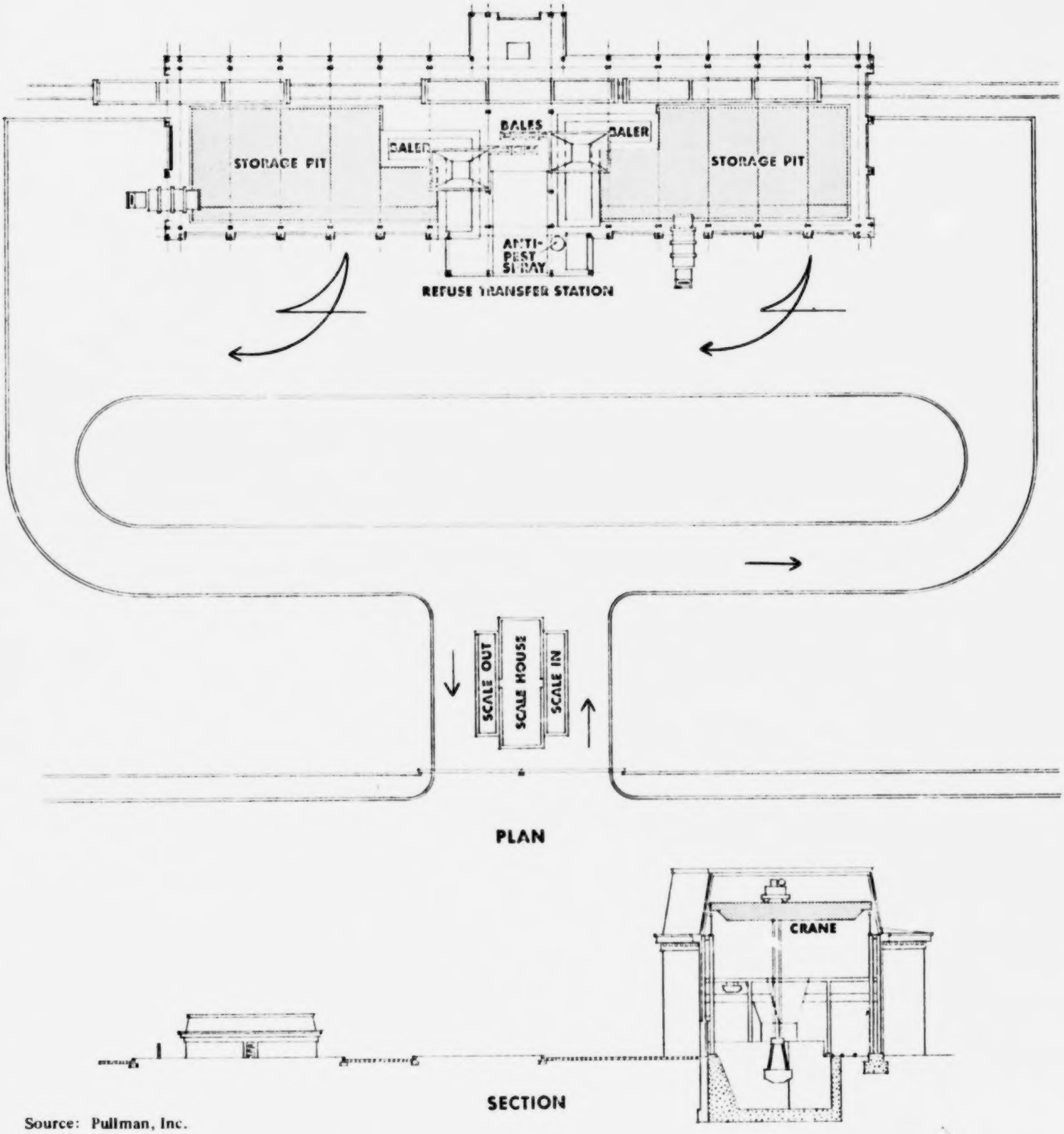


200'
180'
COLLECTION TRUCK DUMPING LEVEL
STORAGE PIT
COLLECTION TRUCKS
STORAGE PIT
TRANSFER TRUCKS

SECTION THROUGH A PORTION OF THE STATION SHOWING THE LEVELS OF OPERATION.
THE DESIGN TAKES ADVANTAGE OF THE VARIOUS ELEVATIONS AFFORDED BY THE LOCATION OF THE SITE ON A HILLSIDE.

FIGURE 6

HERRINGBONE LAYOUT, 5,000 TON SAN FRANCISCO, CALIF., TRANSFER STATION


BALES
BALER
BALER
STORAGE PIT
STORAGE PIT
ANTI-PEST SPRAY
REFUSE TRANSFER STATION
SCALE OUT
SCALE HOUSE
SCALE IN
PLAN
CRANE
SECTION

Source: Pullman, Inc.

FIGURE 7

PLAN VIEW OF TRANSFER STATION AND BALING PRESSES requires at least two entrances, exits, and scales, and, in addition, weighing operation which do not require more than 50 seconds per truck. This speed of operation is feasible, based on commuter ticket, tollway, and industrial production control experience. Therefore, it can be concluded that truck waiting time, even outside a high volume station, should be rare if causes not associated with the station are excluded.

Many variable factors contribute to systems design. The data in Table 8 show station capacity variations as a variable of one factor–net load per truck. Collection management decisions have a direct impact on a rail-haul operation. For example, a change in the collection truck purchase policy and/or the route structure might affect both the net load per truck and the schedule of truck arrivals at the transfer station. In turn, the tonnage delivered during a peak load day by collection vehicles determines the size of the pit required. Furthermore, "total-tonnage delivered" influences decisions on working time and the required speed of operations. Using simulation techniques, with realistic data inputs, it is possible to pinpoint both the opportunities and limitations of a given system.

For the purposes of this investigation it was decided to focus primarily on two transfer station sizes–100 tons and 500 tons per 8-hour shift. A 100-ton station could handle from 10 to 25 trucks and a 500-ton station from 50 to 125 trucks if each truck makes two trips a day, depending upon the net load per truck.

Experience indicates that these two sizes of transfer station would be well suited to the existing organization of the collection efforts. Many solid waste jurisdictions operate fewer than 50 trucks and large jurisdictions are structured into collection districts or wards which, as a rule, provide the base for a fleet of trucks also numbering fewer than 50.

On the other hand, the 500-ton per 8-hour shift station would be suitable for the heavy demand situations and for any consolidations that might be desired in the organization of collection activities. By enlarging the pit and the truck/station interface, station capacity can be boosted to 200-300 or 1,000-1,500 tons per day respectively simply by adding a second or third shift to the operation.

Inherent to the design of the transfer station must be provision for loading the rail-cars and spur trackage for loaded and unloaded cars. Mobile container carriers or fork lift trucks may be used for loading.

Processing

The basic purpose of processing solid waste for rail-haul is to improve the cost/performance relationship of the over-all operation including transport, disposal, and environmental control. Furthermore, processing will facilitate handling, storage, or material-handling operations that may be required at various geographic points. The following are major system development factors.

Type of Material. A solid-waste rail-haul system should initially accommodate as great an amount and

TABLE 8

CAPACITY VARIATIONS IN A 12-STALL TRANSFER STATION BASED ON INCREASES IN THE NET LOAD PER TRUCK

	CAPACITY VARIATIONS			
	72 Incoming Trucks per hour		144 Incoming Trucks per hour	
Net Load Per Truck (Tons)	Per Hour (Tons)	Per 8-Hour Shift[1] (Tons)	Per Hour (Tons)	Per 8-Hour Shift (Tons)
2.0	144	1,152	288	2,304
2.5	180	1,440	360	2,880
3.0	216	1,728	432	3,456
4.0	288	2,304	576	4,608
5.0	360	2,880	720	5,760

[1] The calculations are based on the assumption that the trucks arrive at the frequency indicated throughout the operating time of the station.

variety as possible of household and municipal refuse. To optimize material handling, transport, and disposal systems, homogenization is desirable. This permits effective handling of combinations such as food scraps, household wastes, oversized furniture, and large boxes without requiring oversizing of equipment with correspondingly increased investment and operating costs.

Transport. The key to transport economics is maximum utilization of the transportation equipment, i.e., maximum payloads per unit of transport. Since the density of unprocessed household refuse averages less than 10 lb/cu. ft., both homogenization and densification are desirable. In principle, the denser the materials and the better the utilization of the transport space, the lower the ratio of deadweight per car or train to the net load; correspondingly, the greater the payload per unit of transport, the lower the transportation cost. The value of unit size standardization has been proven by industrial experience in bulk material handling and transport. However, there, as well as in the solid waste field, the processing is or must become an integral part of the total system

Landfill. Space needs, earth moving, and cover requirements represent significant cost factors. Savings achievable by processing for volume reduction can be significant.

Environmental Control. Processing may be used as a tool to produce more favorable disposal characteristics. For example, processing of solid wastes into the form of stable bales reduces or eliminates nuisances, such as blowing paper.

In general, processing of the input materials may affect the feasibility, configuration, and practicality of solid-waste rail-haul. This involves a complex set of objectives. However, the main objective is reduction in volume or increase in weight per unit of volume to minimize shipping and material handling costs. This can be accomplished most suitably by physical methods which can reduce or eliminate void at the interface of the solid materials and within solid waste items.

The limiting condition for volume reduction is the volume of the voids in the wastes. Only extremely rigorous methods, such as compaction under enormous pressures, change basic properties of the solids which in turn change the volume of the solid portion of the wastes. In the absence of changes in the properties of the solids, all that is accomplished is the squeezing out of air and liquids contained in the voids.

Since material properties are not affected by normal physical volume reduction methods, the weight of an individual load remains essentially the same after the volume reduction process. Consequently, the relationship between reduction of volume and increase in density is quite simple when no losses of the materials occur as a result of processing. If the volume is reduced by a factor of three, then the density increases by a factor of three. However, since solid waste mixtures contain solids of different specific weights but of identical volumes, the densities of the individual lots may vary appreciably. This holds true irrespective of whether the mixture contains the same or a different amount of void space. Therefore, it is possible that the weight per unit of volume of a given densified load of waste may be higher than that of another, even if the volume reduction ratio of that load is much lower.

The densities (pounds per cubic foot–lb/cu.ft.) which can be expected for very densely packed solids approximate those obtained for solid blocks containing the same materials. The approximate densities of a selected number of such common solids are listed in Table 9; these values can be used to predict the average density of bales (assuming elimination of all voids.) For example, bales made up solely from paper wastes could have an average

TABLE 9

APPROXIMATE DENSITIES OF COMMON SOLIDS AT 20°C

Solids	Density Range (lbs/cu.ft.)
Paper	43–71
Metal	
Aluminum (alloys)	165–182
Iron (alloys)	430–530
Copper (alloys)	500–550
Glass	150–182
Porcelain	160–190
Plastic	66–120
Wood	12–71
Leather	48–65
Rubber	60–110
Cereal	26–48
Fats	57–61
Wool	50–82
Masonry	100–162
Brick	88–125
Concrete	100–144

density of 57 lb/cu. ft. On the other hand, bales made up of steel scrap could have an average density of 480 lb/cu. ft.

In the absence of any swelling, moisture absorbed by a solid does not produce a measurable increase in the volume of the solid, but it does add to its unit weight. As a result, the densities of solids may vary widely.

Weight can be increased more than 50 percent if the wastes contain a large proportion of highly moisture-absorbent materials such as paper and textiles.

In the absence of voids, dry mixtures of wastes containing a variety of different materials in different proportions should have densities which are between the minimum and maximum values indicated in the table. Thus, it may be calculated that the densities of household mixtures, in the absence of voids and moisture, are in the vicinity of 80 lb/cu. ft. However, solid wastes do contain moisture and therefore the overall density of a waste mixture is affected not only by voids, but by its liquid content.

Measuring the effectiveness of densification must take these factors into account:

a. The decrease in volume achieved by a volume reduction process will depend on the air-to-solid ratio in the waste before and after processing. Since the initial ratio is likely to vary from load to load, different values are to be expected for individual waste mixtures.

b. If a single load of wastes is considered, the increase in density, after volume reduction, would be proportional to the decrease in volume. However, different loads of waste reduced in volume by the same amount will rarely have the same density or weight per unit of volume. Equal weights can only be expected if the materials contained in the same space have the same specific densities.

c. If the wastes also contain absorbed moisture in addition to the solids, then the obtainable density will be increased, reflecting the contribution of the liquid to the total weight. This contribution could be appreciable, both for processed and unprocessed wastes. However, in the absence of swelling, it would not affect the volume of the densified wastes.

d. Absence of voids and displaceable liquids permits densities that may range from about 57 pounds for paper to about 480 pounds for iron scrap/cu.ft. Estimates of the volume reduction achievable for solid waste mixtures range from about 3:1 to 10:1. Under optimum conditions, typical household solid waste *mixtures* can be densified to about 80 lb/cu. ft.

Methods that might be employed for processing solid wastes for rail-haul should be anlayzed primarily in terms of: a. suitability for as large a variety of materials as possible, b. volume reduction, and c. cost. The two principal methods of densification are size reduction and compaction. Both were initially evaluated. Compaction was subsequently investigated in a separate demonstration project because of the promising results obtained by the exploratory research conducted in connection with this study.

Size Reduction

In recent years there has been considerable application of size reduction to solid wastes as a pre-processing method. It has been utilized in composting operations and in scrap processing (particularly auto hulk processing) to reduce the size of bulky items. It has also been used occasionally as a pre-processing method of incineration to facilitate combustion by increasing the surface area and therewith the volume of the wastes to be burned. More recently, size reduction has been used to decrease the volume of existing voids in wastes.

Size reduction is not always a method of volume reduction. For example, a reduction in volume of dense materials, such as logs or metal bars, may not be achieved by size reduction. In fact, such items, when shredded, may increase in volume. Solid wastes such as household refuse, however, contain a high proportion of products which contain large voids. Therefore, size reduction can achieve a decrease in volume by making the large voids in waste items (large empty containers for example) into smaller ones. It should be pointed out, however, that size reduction does not eliminate all voids.

Many existing transfer stations utilize a tracked tractor on the floor of the receiving pit to crush large objects and prepare such objects for handling. Such an effort or some other means of reducing oversized material to a size which can be handled by the disposal system will be needed at transfer stations.

Analysis of the potential application of size reduction for the rail-haul of solid wastes revealed that a comprehensive theory of size reduction has not yet been developed and that the principles by which the different types of solids disintegrate appear to be poorly understood. In fact, the two theories postualted by Rittinger and Kick which are still widely used in the design of size reduction equipment were introduced in 1857 and 1883. These theories are mutually contradictory. Rittinger postulated that the useful work done in crushing and grinding is directly proportional to the new surface area produced and inversely proportional to the product diameter. The Kick theory is based primarily upon the stress strain diagram of cubes under compression. Fred C. Bond[3] in 1952 proposed a third theory, that the total work required for crushing and grinding varies inversely as the square root of the product size.

Most of the available size reduction equipment tends to be cumbersome. It has a high power requirement and most of its energy is dissipated as waste energy rather than as disintegration energy. In addition, many different types of equipment, utilizing different size reduction principles, have been used to meet specific disintegration property requirements of identical or similar, i.e., homogeneous materials.

The lack of theoretical background and the heterogeneity of solid wastes pose a difficult problem for the development of "tailor-made" size reduction machinery. The use of several size reduction principles is required because of the different disintegration properties of the various solid waste materials. For example, hard and brittle materials, such as glass, ceramics, and many construction wastes, break easily under impact. These materials can be easily disintegrated by the use of impact equipment such as hammermills. On the other hand, soft, elastic, and fibrous materials such as plastics, rubbers, metals, paper, textiles, and wood are best reduced by a cutting or shearing action which requires equipment of the kind used in the rubber and wood industries.

Size reduction equipment which is to be used to process nonsegregated solid wastes also must be constructed to handle the hazardous and nuisance materials occasionally found in solid wastes. Clogging, fires, and even explosions can be encountered in the size reduction process. Most of the size reduction units presently in use were originally designed for other purposes. However, some models have been modified for solid wastes; a few incorporate in their design two sections – one for crushing and one for shredding. In most cases, however, it has been found necessary to provide some degree of separation of wastes such as the elimination of large items prior to the size reduction process to avoid major difficulties.

The design of solid waste size reduction equipment is generally based on impact or crushing principles. Most of the machines in use are adapted hammermills of the hammer-crusher or impactor design. A few are based on tearing and/or cutting principles.

The difference between crushers and impactors is found principally in the speed of operations and clearances. The crusher operates at a slower speed than the impactor, and it is designed with higher clearances.

Hammermills come in many different types. Those used for coarse and intermediate crushing are, as a rule, heavy duty, low-, or intermediate-speed units. High peripheral speed units are generally used for pulverization rather than crushing. Heavy duty hammermills are employed for the crushing of materials which are essentially nonabrasive. Capacities range from less than one to about 1,200 tons an hour. Size reduction by the heavy duty mill, illustrated in Figure 8, is achieved by impact between the hammers, breaker plates, and the material, and then at the pinch points between the hammers and screen or grate bars.

These mills are horizontal or sometimes vertical shaft units which carry a series of pivoted or hinged hammers. Some have adjustable breaker plates. The fineness of the product can be adjusted by changing the clearance between the hammers and the bars or the breaker plates, and the size of the discharge opening. Large items are recycled until the desired fineness is achieved.

Impactor hammermills are recommended when large reduction ratios (up to 35:1) are required for materials that shatter on impact, such as rocks. The reduction process can be achieved at high or low machine speeds. The most effective method of crushing brittle materials with a minimum of fines is to run the machines at low speed and in a closed circuit.

There are several types of impact hammermills available with fixed or adjustable breaker plates: the reversible impactor, the twin-rotor (Fig. 9), and the ring-type impactor. The reversible impactor has been used for size reduction of rocks and limestone. The capacity of this unit ranges from a few hundred pounds to 1,500 tons an hour. Uncrushable materials such as scrap iron are removed by centrifugal force. Twin-rotor type impactors with manganese steel hammers and capacities up to 200 tons an hour have been used for the size reduction of wet and sticky materials.

Ring-type units with capacities up to 1,800 tons an hour and designed for brittle materials such as bituminous coal apply ring hammers and crushing

[3] The Third Theory of Comminution, Bond, Fred C. p. 484-494. Mining Engineering, May 1952.

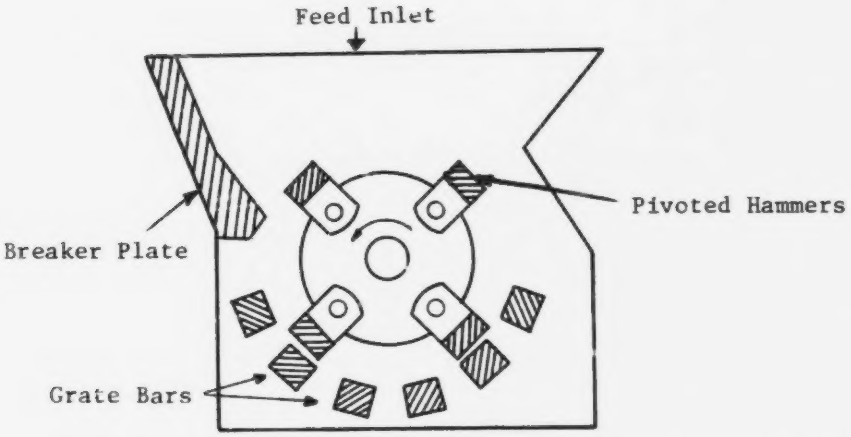


FIGURE 8
HEAVY DUTY HAMMER CRUSHER

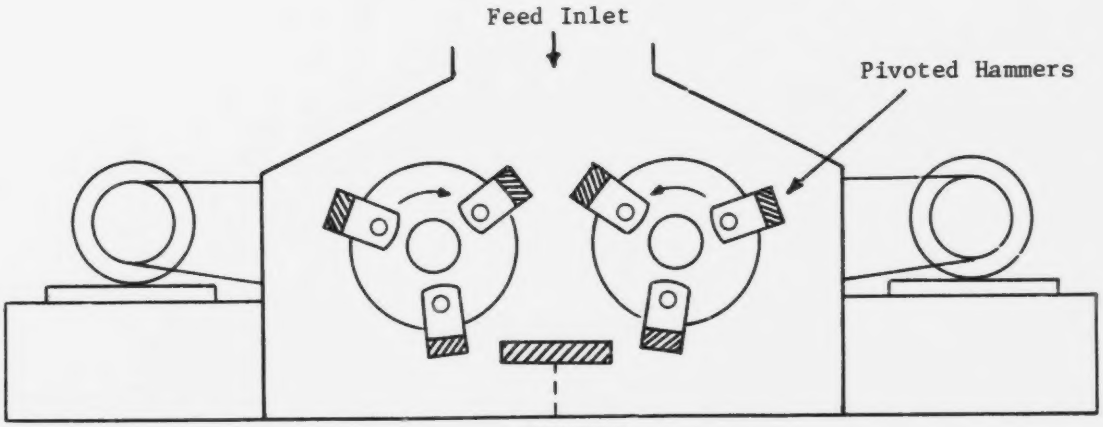


FIGURE 9
TWIN-ROTOR IMPACTOR

rings to accomplish size reduction by crushing. The hammers and rings are hung from suspension shafts and roll slowly over the feed, cracking and shattering the materials by a "rolling compression" without rubbing. The ring-type machines may be equipped with plain or toothed rings.

Hammermills used for fine pulverizing generally operate the hammers at high peripheral speeds and impinge the material against a cover. Coarser product sizes, however, can also be obtained with these machines by reducing the speed and therewith both the force and frequency of impact; by increasing the clearance of the screens, and by changing their configuration in the mill.

"Non-clog" hammermills are employed for materials which are reducible by crushing but which can be wet and sticky. These mills utilize a traveling breaker plate which forces the feed into the crushing path of the hammers. These units have capacities up to about 1,500 tons an hour. They are primarily used in the lime, chemical, quarry, and ceramic industries.

The disintegrator hammermills usually combine the actions of attrition, cutting, and impact in one unit. The hammers are, as a rule, fixed rigidly. However, there are also units which use swing hammers. The basic design consists of a rotor running inside a 360° drum-type screen enclosure. The materials processed in disintegrators are frequently tough and elastic or wet, rather than hard and dry, and the feed rate is quite low. The materials include plastics, food, chemicals, and wood chips. The hammertip speeds in different units range from about

1,000 to 22,000 feet per minute and the power requirement of large units is about 200 horsepower.

Flail mills are also impact units. They are horizontal, single rotor units with a studded shell and hammers attached to the rotor by means of chains forming a flail. The flails beat the material and in this process break up the incoming feed. This type of impact unit accepts garbage, cement blocks, and steel plates. Although frequent replacement of the flails may be necessary, flails are inexpensive and easy to replace.

Knife blade or cutting type hammermills operate at high speeds. Hammers of knifelike construction are mounted on a rotor, with the blades in close proximity to a sizing screen. Knifelike hammers, which take a fraction of the cross section of a mill, tend to cut or granulate a product akin to the hammer and chisel principle with a minimum of fines. To minimize abrasive effects on the hammers, tungsten carbide or similar hard-surfaced hammer tips are used.

A *crusher shredder* combination is a two-stage piece of equipment which is based on the principle of a roller crusher and a rotary cutter. The material is first crushed and flattened between rolls and then shredded by rotary knives.

Roller-crushers usually have two rolls revolving, as shown in Figure 10, toward each other at the same speed. Large diameter rolls are required for large feeds. Tension springs are used to exert pressures from about 6,000 to 40,000 pounds/linear inch of roll face. This is equivalent to a crushing strength of 18,000 to 120,000 pounds/square inch.

The rotary cutters employed in this combination are primarily used in the plastics industry. Some of these cutters are capable of cutting 200-pound blocks of thermoplastics as well as 80-pound synthetic rubber bales. Knives are utilized liberally, as illustrated in Figure 11, to provide maximum cutting action. For example, cutters with as many as five cutter knives set in a herringbone pattern have been used in the size reduction of leather, rubber, plastics, rags, bark, and metal foil. In some cutters the flywheels are provided with shear pins to minimize damage from materials such as tramp metal.

A novorotor type grinder is shown in Figure 12. It is a twin-rotor impactor, each rotor operating in a different direction. The feed enters the unit through a centrally located opening and is then projected from one rotor to the other until it is sufficiently reduced to pass between the rotating bars which form the base. The rotors, driven by individual 500KW motors, revolve at about 3,000 rpm in units built for a throughput of six tons an hour. The rotating bars are chain driven outside the body of the machine. Maintenance costs for one twin-rotor machine are claimed to be substantially less than those for two hammermills. The Novorotor grinders pulverize glass, tear up textiles and carpets to strings, and shred paper and cardboard to pieces of about two inches. Novorotor type pulverizers for bulky wastes have feed openings of about 60 x 120 inches and a capacity of up to about 200 cubic yards per hour. Materials reduced by these machines include boxes large cans, rocks, and furniture.

There are many types and models of equipment now available which may be considered for the size reduction of solid wastes. Examples include

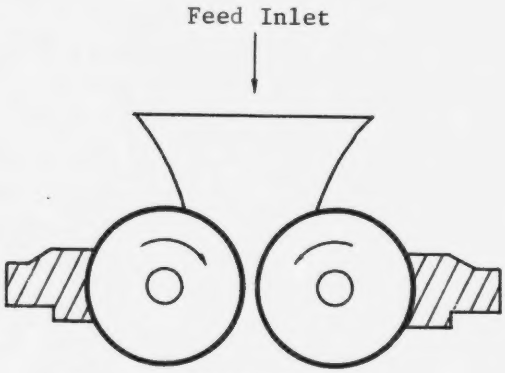


FIGURE 10
ROLL CRUSHER

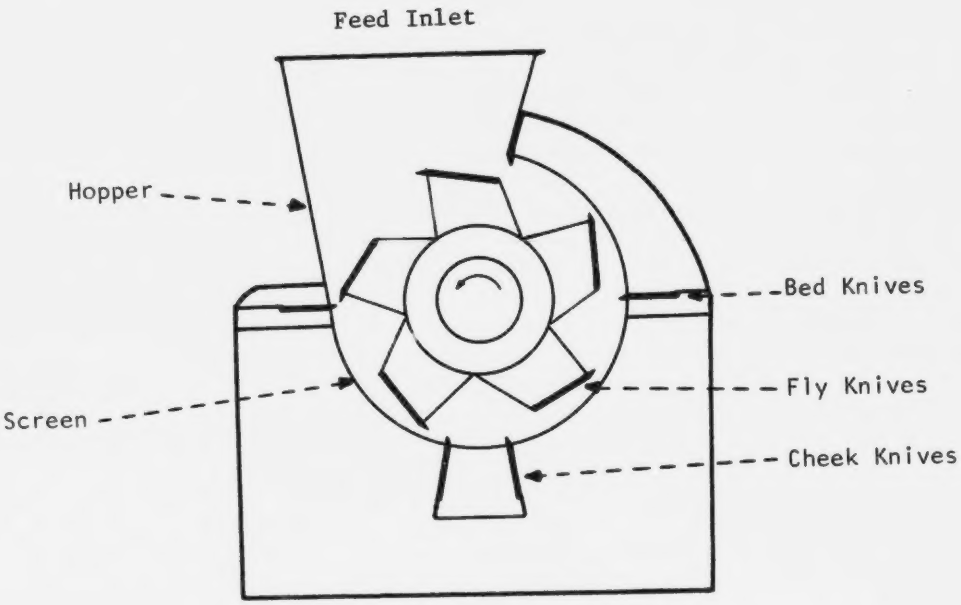

Feed Inlet
Hopper
Bed Knives
Fly Knives
Screen
Cheek Knives

FIGURE 11
ROTARY KNIFE CUTTERS

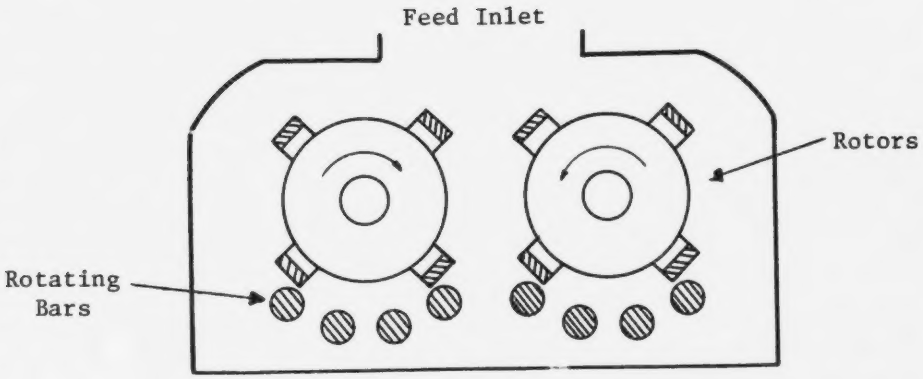

Feed Inlet
Rotors
Rotating Bars

FIGURE 12
NOVOROTOR GRINDER

Pennsylvania and Jeffry crushers, Volund and Gondard pulverizers, Tollemache pulverizers and sorters, Link-Belt grinders, Bulldog shredders, Joy crusher-disintegrators, refuse shears, Munro-Roto breakers, Eidal Eaters, rasping machines, and Cobey composters.

Noise and dust are often significant problems to be considered in size reduction. Noise and dust are of importance with respect to occupational hygienne, maintenance, and the construction of the facilities. Hammermills, especially, are quite noisy and the dry grinding of refuse will always produce a substantial amount of dust. Wetting of the refuse naturally would reduce the production of dust; however, it will simultaneously enhance the corrosive properties of the wastes, which depend on the chemical composition and moisture content of the grind. These corrosive properties, together with the abrasive properties of solid wastes, could take an appreciable toll in metal wear and thus increase the operating cost.

Metal wear can be expressed in pounds of metal wear per kilowatt-hour. This permits an equipment comparison which takes into account differences related to the variations in properties of materials subjected to size reduction.

The cost of metal wear in refuse grinding can be high. Severe damage is likely to occur if the machines are not designed to handle difficult materials ("scrap losses"). Normal wear results from abrasion and dissolution. Metal losses in wet grinding are usually up to ten times higher than those in dry grinding or crushing. These losses arise from the dissolution of iron metal parts which are in contact with the wet grind. The dissolved iron forms ions which interact with the hydroxyl group of water. This results in an increase in the acidity of the wet grind and thus enhances the corrosion of the metal parts. The loss of metal becomes appreciable when the pH is below 5.5. In some cases a pronounced increase in metal loss can be produced by the buildup of an electrochemical potential at the interfaces between the grind and the metal surfaces in the machines. In these cases the rate of dissolution increases and rapidly reaches values which are much higher than those encountered in chemical dissolution alone.

Dissolution of metal does not occur in dry grinding. Instead, the abrasion of metal results from either mechanical impact or friction. The effect of material abrasive hardness upon metal wear in impact crushing is generally much more pronounced than in other methods of size reduction. In general, hard materials, coarse particles, and fast grinding motions are conducive to abrasive wear. Mill wear becomes critical in high-peripheral-speed equipment, particularly high-speed close-clearance hammermills. Within normal operating ranges of some mills the metal wear is roughly proportional to the mill speed. However, different types of equipment performing the same function exhibit differences in metal wear. It has been estimated that metal wear in crushing rolls is nearly twice that in jaw crushers, and that the wear in crushers is higher than in grinding mills.

Different parts of the same unit can be affected in different proportions both in wet and dry grinding or crushing. In wet ball mills the ball wear by abrasion and dissolution is often found to be about 13 times that of the liner wear; in dry ball mills the ball wear is about 10 times higher than that of the lining.

An effective way to reduce metal wear due to corrosion or abrasion is the substitution of parts with a high wear resistance for those with low wear resistance. Stainless steel is found to reduce wear appreciably in wet grinding, nickel alloys are also known to reduce metal wear in wet grinding, and even more so in dry grinding. Similarly, alloys containing chromium, molybdenum, and manganese are found to improve the wear resistance of size reduction equipment, such as hammermills and cutters. Tungsten carbide tips are found to reduce wear on knife-type hammers. However, due to the increase in the acquisition cost of parts made from these materials, it is always necessary to balance investment against the maintenance cost.

Available metal wear data are rather limited. But, some results related to: a. the method of size reduction, b. different parts of the units, and c. their relationship to the abrasion index have been published[4] and are given in Table 10. The first column in the table lists different materials in the order of increased abrasion index irrespective of the grinding method or equipment. The table also illustrates the difference between wet and dry grinding, and the relative effect of grinding on individual parts of the equipment. The wear averages given include the scrap losses which are estimated to be approximately 60 percent of the total metal wear for crusher liners, 35 percent for ball mill liners, and about 20 percent for crushing roll shells.

Operating and maintenance costs of size reduction equipment depend primarily on the power consumption and metal wear of the equipment. These, in turn, depend on the design of the

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[4] F. C. Bond, *Chemical Engineering Progress*, Volume 60, No. 2, 1964.

TABLE 10

WEAR AVERAGES, lb/kw-hr

Material	Abrasion Index	Wet Grinding[1]		Dry Grinding		
		balls	linings	balls	crushers	rolls
Dolomite	0.0160	0.060	0.0053	0.0050	0.0220	0.0160
Shale	0.0209	0.061	0.0054	0.0051	0.0221	0.0161
Limestone	0.0320	0.090	0.0074	0.0088	0.0230	0.0215
Magnesite	0.0783	0.138	0.0112	0.0140	0.0270	0.040
Copper Ore	0.1372	0.178	0.0140	0.0190	0.0333	0.060
Gravel	0.2879	0.228	0.0176	–	0.046	0.094
Aluminum	0.8911	0.340	0.0248	–	0.100	0.198

[1] Wet grinding: moisture content exceeds 30% by weight

equipment and the material properties of the equipment components. The cost of size reduction operations is also affected by the nature of the feed material and the fineness of the resulting product.

The operating cost for electric power and maintenance of high capacity hammermills with wide screen openings, based on manufacturers' information, approaches $1.00 a ton for mills capable of processing several hundred cubic yards or about 30 to 60 tons of wastes an hour. The capital cost of such large units is estimated to range from $300,000 to $500,000. The replacement costs for damaged metal parts, in particular, the hammers and graters, are reported to range from 20 cents to 35 cents a ton.

A study of experience with 12 different size reduction machines used to reduce residential wastes indicates a cost of 80 cents to $1 per ton of refuse processed (35 percent for power, 40 percent for maintenance, and 25 percent for straight depreciation, excluding interest and salvage). The wastes were sometimes prepicked, but in all cases oversized items were excluded and the nominal end-product size was about six inches. Labor costs have not been included in the estimates because of wide variations in local conditions.

Compaction

The simplest physical method of obtaining low volume, high density bundles of solid wastes is the compaction of the materials in presses. During this process the materials are crushed and flattened and the air which occupies the voids is expelled. The extent to which crushing and flattening takes place depends on the pressure exerted and on the counter pressure developed by the compressed material. In the optimum case, voids are minimized and the resulting close contact between the materials facilitates adhesion and interlocking between the solids, thus forming, in the experimental bales produced in the demonstration project, a cohesive, stable structure. The density of well-compacted bales is likely to be about two to three times that of the same material subjected to size reduction and therefore could occupy only one half or less of the volume required for shredded refuse.

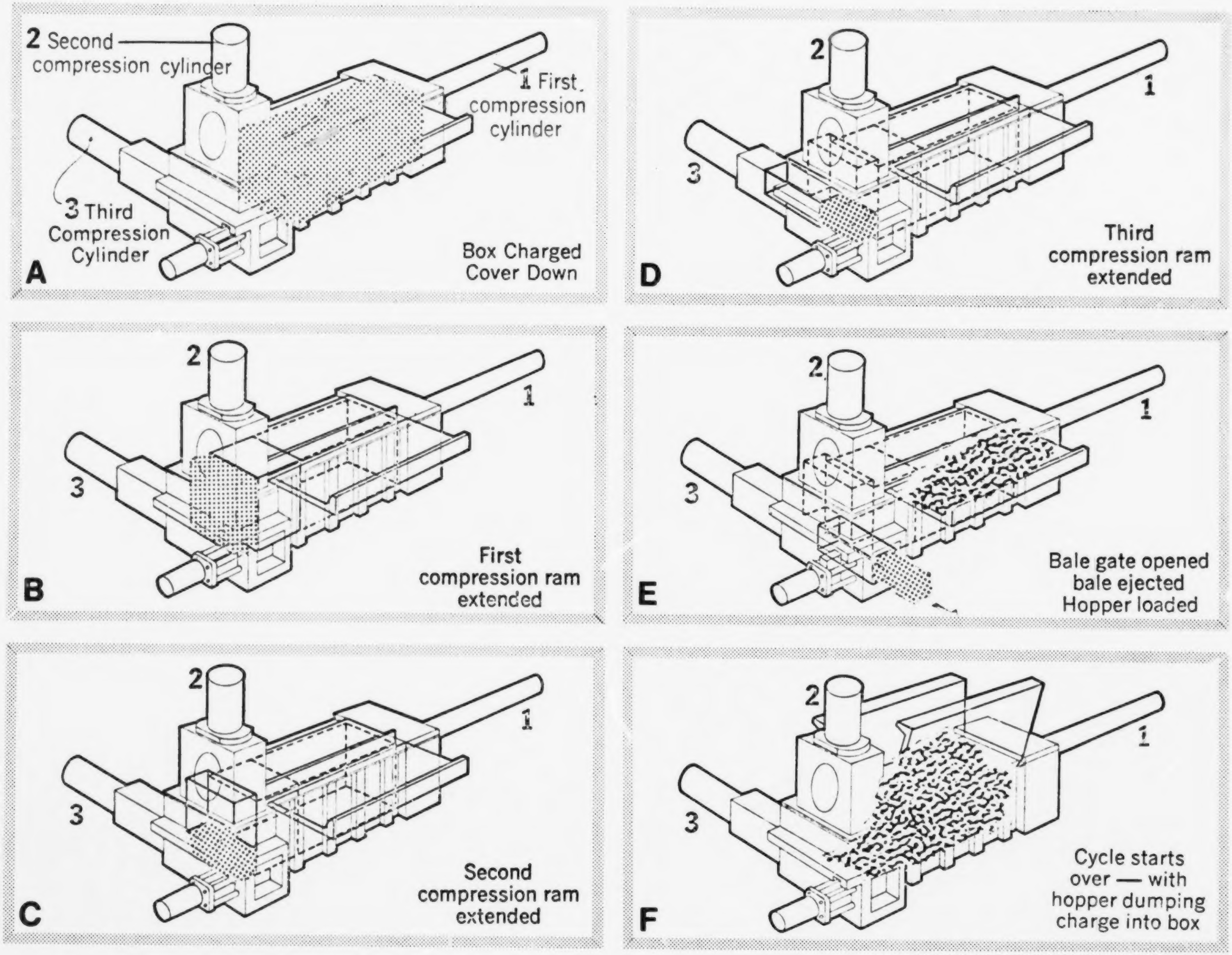
Figure 13, Operating Cycle of High Density, Multiple Stroke Baling Press, shows the six steps of the operation of a typical metal baling press

A series of preliminary solid waste compaction experiments in small presses and metal balers capable of delivering relatively high pressures were performed as a part of this study. The results and conclusions are summarized as follows:

a. Compression of increments of batches of solid wastes resulted in poor compression at the interface of each compressed portion. This effect persisted even when the final pressure was increased to 18,000 psi, thereby indicating that a discontinuous feeding of materials requiring intermediate compression should be avoided.

b. The magnitude of the contact surface applied pressure needed for suitable compaction of residential refuse, including oversized items, appears to be in the vicinity of 2,500 psi. An increase in applied pressure above 2,500 psi did not produce an appreciable increase in the density (volume reduction) nor in the stability of the bale. However, the addition of special materials, such as binders, and changes in the size and configuration of the bales might necessitate the utilization of presses with higher pressure capacities.

c. Refuse with a high moisture content (>30%) disintegrated after removal from the compaction press. However, ordinary


A
2 Second compression cylinder
1 First compression cylinder
3 Third Compression Cylinder
Box Charged Cover Down
B
2
1
3
First compression ram extended
C
2
1
3
Second compression ram extended
D
2
1
3
Third compression ram extended
E
2
1
3
Bale gate opened bale ejected Hopper loaded
F
2
1
3
Cycle starts over — with hopper dumping charge into box

Source: Penn Central Transportation Company

FIGURE 13

OPERATING CYCLE OF HIGH-DENSITY MULTIPLE-STROKE BALING PRESS amounts of moisture in household refuse are beneficial in the compaction and/or extrusion of wastes containing large amounts of paper. Slightly moist (20-30%), extruded, or pressed bales with a high paper content appear to be more stable than bales made of of fully dried materials.

d. Improved stability and good cohesion were obtained with samples of refuse which included metal. The improved stability of bales in the presence of metal is attributed to the interlocking ability of the soft metals. This finding could be utilized in the development of appropriate baling techniques, if a greater than normal stability of the bales should be desired.

e. Spring-back, immediately after compaction, was experienced by bales containing primarily paper, or samples consisting of leaves and green twigs. In the latter samples the twigs uncoiled and the sample disintegrated within a short period of time. Spring-back, i.e., the reintroduction of voids, can affect the stability of the bale required, the compression speed necessary, and the system-associated material handling and space requirements.

f. Glass was always crushed into small fragments during compression. Glass particles on the outside of the bale could present some hazard, since they appear to adhere poorly to the outer surface of the bale.

g. Density of compressed samples of similar composition showed little variation with an applied pressure above 2,500 psi. large variations in weight were observed in samples of different composition. Bales of light weight materials, such as paper, will of course weigh less than bales made of heavy materials, e.g., metals and their alloys. The weights of compressed and/or extruded samples, some of which included oversized solid wastes, ranged from approximately 60 to 170 lb/cu. ft. Some of the compacted samples appeared to contain significant amounts of moisture. The exact amount of moisture and it's contribution to the weight of the sample could not be determined in those exploratory experiments. Because of wide variation of unit weights of solid wastes, it is apparent that either the size or the weight of the bale will have to vary within certain limits unless the input is homogenized.

h. Shredding household refuse before compaction, as compared to direct baling, did not appear either to aid the compaction process nor to contribute to the stability of the bale.

Solid-waste density benchmarks are fundamental to the processing of solid wastes for rail-haul. Data consolidated from a variety of sources are shown in Table 11, Densities of Residential Refuse Achieved by Different Processing Methods. Wide variations for individual loads may be expected.

Because of the great variations in the densities of the input materials, it appears advantageous to use a multi-stroke compression approach for the high-pressure compaction of solid wastes. Considering existing presses, the metal scrap balers or similar compaction devices appear to come closest to the requirements for a high-pressure refuse compaction device. Existing presses are not tailormade for high-pressure compaction of solid wastes since they were designed for different compaction purposes. Thus, the cost data presented in this section are based upon guideline data derived from existing presses and indicate only a very general order of magnitude.

Metal scrap balers are usually three-stroke compaction devices which, in the final compression stroke, apply a force of 2,000 to 3,000 psi on the materials to be compressed. The operating speed of these machines may range, on the average, from 30 to

TABLE 11

DENSITIES OF RESIDENTIAL REFUSE ACHIEVED BY DIFFERENT PROCESSING METHODS

	Density Lbs./Cu. Yd.
Loose refuse, no processing	100 to 200
Refuse from a compactor truck after being dumped	300 to 400
Refuse compacted in a compactor truck	400 to 700
Shredded refuse	300 to 600
Shredded refuse baled in a special paper baler and strapped	800 to 1100
Refuse compressed in a metal scrap baler without shredding or strapping	1600 to 2000

120 seconds per cycle, and the useful service life is often quoted to exceed 20 years. A broad range of hydraulic presses is frequently specified at 100 to 300 horsepower per machine with the full power being needed during less than 50 percent of the operations. The investment cost, excluding interest and financing charges, is reported to be in the range of from $250,000 to $400,000, and the annual maintenance expenditures are estimated to run from two to three percent of the investment cost. The basis for exploratory and developmental calculations (1968-1969 price levels) is as follows:

Investment per compression device is $500,000.

Useful service life is 20 years.

Straight depreciation cost is $25,000 a year; no salvage value is assumed.

Power requirements are 500 horsepower, and it is assumed that the full power will be required continuously.

Electricity cost is 1.5 cents/kilowatt hour.

Compression device cycle time is 60 seconds.

Processing throughput is about one ton a minute or 156,000 tons a year in one-shift-per-day operations (six shifts per week, 8 hour per day.)

Based on the above assumptions and a three percent maintenance factor, the following cost per ton can be calculated:

Investment depreciation	$0.167
Maintenance	0.096
Electricity	0.094
	$0.357

Under the assumption that two percent maintenance expenditures and two shifts a day, the calculations would run as follows:

Investment depreciation	$0.084
Maintenance	0.032
Electricity	0.094
	$0.210

The above costs, like those quoted for size reduction, refer only to items directly attributable to the processing equipment. They exclude any financing charges and interest, return on investment, labor, and other associated transfer station expenditures, such as foundations. Nevertheless, high-pressure compaction of solid waste appears economically attractive.

MATERIAL HANDLING

The results of several surveys suggest that, on an industry-wide average, material handling accounts conservatively for about 30 percent of the total cost of producing a finished product. Thus, it is desirable to minimize the material handling functions through the layout of the process.

Prime factors to be considered in equipment selection are the performance requirements which must be met. These include: the capacity (weight and/or volume), the speed, and the distance which the equipment has to travel.

A number of important material properties which must be taken into acocunt in the handling of unprocessed and processed solid wastes are given in Table 12, Material Handling Characteristics of Residential Wastes.

An evaluation of the material characteristics of the three types of residential wastes indicates that similar material handling methods and equipments can be used for unprocessed and shredded wastes. The main differences are that shredded wastes do not contain large size items which must be accommodated by the equipment, and that lower volume capacity equipment will be required for shredded than for unprocessed wastes. Other differences which must be accommodated are the high content of fines in the shredded material which by improper selection of method and equipment could create dust problems. In both cases methods utilizing gravity motions on a slightly inclined surface have to be excluded due to the poor flow characteristics.

The mildly corrosive and abrasive nature of the wastes, and the presence of contaminants and sticky materials such as oils, paints and some foods will influence the choice of materials used in construction and for material handling.

Residential wastes, compacted into bales exhibit characteristics of semi-rugged compact materials and can be handled by equipment and methods used for similar formed products. Lower volume capacity equipment would be required to move the same quantity of baled wastes than would be required to move the unprocessed and shredded wastes. Flow methods would not be applicable.

Material handling functions are specified in terms of many variables and within each set of specifications they can be accumulated in various ways. Thus, to cut through the multitude of alternatives, it is necessary to confine the following analysis by use of the following assumptions.

1. Storage Pit for the Incoming Wastes

It is assumed that each transfer station would have, like incinerators, a storage pit for the incoming wastes.

This assumption is made for two reasons: 1. a

TABLE 12

MATERIAL HANDLING CHARACTERISTICS OF RESIDENTIAL WASTES

	Unprocessed (as delivered)	**Processed**	
		Shredded	**Baled**
flowability	sluggish	sluggish	–
density	approx. 6 lb/cu.ft.	approx. 10 lb/cu.ft.	approx. 67 lb/cu.ft.
size & shape	large variations in sizes and shapes of mixture components	less variations in sizes. Different shapes	some variations in size and shape of individual bales
moisture	varying degrees (from dry to wet)	varying degrees (drier than unprocessed)	varying degrees (from dry to wet; drier than unprocessed)
abrasiveness	mildly abrasive	mildly abrasive, (more abrasive than unprocessed)	mildly abrasive
corrosiveness	mildly corrosive	mildly corrosive	mildly corrosive
stickiness	can contain sticky materials	can contain sticky materials	can contain sticky materials
dusts & odors	varying degrees of dusts and odors	very dusty; odorous	little dust (from spillage); odorous

storage pit provides a material hold area in case a malfunction occurs in the system; and 2. a storage pit is needed to absorb peak loadings as caused by existing collection practices and to convert the cyclical waste delivery into a steady-flow system input. The case of direct or partially direct dumping from the collection truck into the rail car is excluded by this assumption, because it is considered a special rather than a general rail-haul system configuration.

The storage requirements for the incoming wastes are assumed to be equivalent to the throughput rating of the transfer station.

The corresponding size of the storage pit is calculated on the basis of a waste density of 10 lb/cu. ft. or 270 lb/cu. yd. Due to some packing that will occur in storage because of the weight of the material, it was assumed that the waste material handling density excluded packing conditions.

As a result the sizes of the storage pit would be:

Capacity of Transportation (Tons)	**Size of Pit (Cu. ft.)**
100 tons, 8-hr/shift	20,000
300 tons per day	60,000
500 tons 8-hr/shift	100,000
1,500 tons per day	300,000

These space requirements can, of course, be satisfied by various storage pit configurations. Depending upon local conditions, a storage pit may be deep or shallow, narrow or broad, and long or short. Furthermore, there are interfaces between volumes configuration of the storage area and the material handling required to remove materials from the storage area. For example, it is possible to establish a live-bottom storage pit from where the wastes would be removed – and in this process mixed – by machinery akin to a moving and horizontally operating rotary excavation wheel.

For the purposes of this project, however, it was felt advisable to follow the established incinerator pit experience. This involves the removal of the materials from the pit by crane which also accommodates a mixing of the materials should this be necessary.

2. Location of the Processing Machinery

The processing machinery is assumed to be in or immediately adjacent to the pit. This assumption avoids, like incinerator layouts, unnecessary material handling and travel and the charging mechanisms of the processing equipment are fed by the pit crane.

3. Distance from Pit and/or Processing Area to the Rail Spur

The distance from the pit and/or processing equipment to the rail car loading area can represent a significant operations and cost factor.

For example, almost no material handling would occur if the rail spur would be located immediately adjacent to the pit or processing facility. The pit crane would load the unprocessed wastes directly into the rail car; the shredder would discharge directly; and the press would be constructed to stack the bales in the car with the help of a simple stacking mechanism which, if necessary, could be actuated and powered by a bale ejection ram.

However, like direct dumping, this case is a special rather than a general system development situation. Consequently, rail-haul feasibility should include some provisions for material handling and any decrease in the local material handling demands would, of course, result in a decrease of the system cost and therewith more attractive economics.

The minimum distance from the pit or processing area to the rail spur is assumed to be 250 feet. This assumption is made to facilitate maximum pit access for the collection trucks which is quite important in terms of the total refuse removal cost.

4. Changes in the Elevation of Material Handling Movements

Changes in the elevation of material handling movements are necessitated by both layout and processing requirements. In turn, changes in the elevation affect both the investment and operating cost.

It was assumed that a maximum of two changes in the elevation could occur. The first elevation is required at the pit, i.e., the crane lifts the materials out of the pit. The second elevation occurs in the loading of the rail car and/or container.

Concerning the loading of the rail car it was assumed that unprocessed and shredded solid wastes would be loaded from the top. Since the full height of a rail car extends about 16 feet from the rail, it was concluded that an elevation of 20 feet should be accommodated in order to allow ample room for clearance and for loading over the full width of the car. Baled solid wastes are assumed to be loaded from the side which could involve a change in elevation ranging from 4 to 12 feet.

All other material handling movements are assumed to run level to the ground.

The listed assumptions can be converted into a material handling demand profile for transferring unprocessed, shredded and baled solid wastes into a rail-haul system.

It is apparent from the many variables and interdependences indicated that numerous material handling cases and decision alternatives could be established. A few examples are given in Table 13, Material Handling Requirements, to illustrate the similarities and differences resulting from variations in the transfer approach.

The information in Table 13 indicates that the material handling function can be made relatively simple. The crane operations – and expenditures – are identical for all three systems. Differences occur in the charging mechanisms, the in-station transport, and the loading of the rail car.

To identify material handling feasibility, i.e., to avoid over- or undersign, it is necessary to convert the material handling requirements into reasonable performance specifications for the material handling equipment.

Material handling equipment can be designed or is readily available to meet almost any performance requirements. Some of the material movement characteristics of existing equipment are given in Table 14, Range of Average Performance Parameters. The type of equipment indicated is available with many different performance variations. Furthermore, the service life of the equipment can be quite extensive even under heavy duty operating conditions. For example, cranes and conveyor systems are reported to have operated satisfactorily in excess of 25 years.

The performance specifications for material handling equipment in rail-haul transportations indicate, in view of the above information, major implementation problems will not occur. In developing examples of such performance specifications it was of course necessary to make additional assumptions. These were:

1. Pit Cranes

Type of equipment: Overhead traveling cranes, electric, bridge over middle of pit, bucket or orange peel grapple capacity 5 and 10 cubic yards. Five cubic yard crane is used in 100 ton/8-hr station; 10 cubic yard crane is used in 500 ton/8-hr station.

Density of material: About 10 lb/cu.ft. – pit, 15 lb/cu.ft. – bucket. One cubic yard in bucket carries about 400 pounds of waste: a 5 cubic yard bucket carries about one ton and a 10 cubic yard bucket carries about two tons.

Time available per round trip: 100 tons per 8 hour equals about 13 tons per hour; 13 round trips per hour or about 4.5 minutes per run with a five cubic yard bucket.

TABLE 13

MATERIAL HANDLING REQUIREMENTS FOR TRANSFERRING 100 TONS or 500 TONS OF UNPROCESSED, SHREDDED OR BALED SOLID WASTES PER 8-HOUR INTO A RAIL-HAUL SYSTEM

Transfer Elements	Material Handling Function	Unprocessed	Shredded	Baled
1. Storage pit, 20,000 cu/ft.	Take out 13 tons per hour	Overhead traveling crane	Overhead traveling crane	Overhead traveling crane
2. Storage pit 100,000 cu/ft.	Take out 63 tons per hour	Overhead traveling crane	Overhead traveling crane	Overhead traveling crane
3. Charging mechanisms	Equalize and dimension flow of material	Hopper and distributor	Hopper and distributor (distributor increases incomplexity if more than one shredder is needed)	Hopper and scale, portioning by weight
4. In-station distance of 250 feet	Movement level to ground	Conveyor	Conveyor covered because of dust	Industrial Fork Lift Truck
5. Loading of rail car	Elevation, stop or storage to allow for movement of railcar, if more than one is needed	Part of Conveyor system, small hold hopper	Part of Conveyor system, small hold hopper	Equipment already given by industrial fork lift truck

TABLE 14

RANGE OF AVERAGE PERFORMANCE PARAMETERS OF SELECTED MATERIAL HANDLING EQUIPMENT

Type of Equipment	Selected Performance Characteristics Load (tons)	Speed (fpm)
Electric wire rope hoists	1-5	15-80
Industrial cranes	up to 15	10-35
Traveling cranes	up to 300	trolley 75-150 bridge 100-300
Flight conveyor	several 100/hr	100
Apron conveyor	several 100/hr	100
Belt conveyor	several 1,000/hr	700
Drag chain	10/hr	10-20
Industrial fork lift truck	up to 40	up to 900

Five hundred tons per 8 hour equals about 63 tons per hour; about 31 round trips per hour or slightly less than two minutes per run with a 10 cubic yard bucket. This time includes three seconds for dumping and 6 to 10 seconds for grabbing.

Pit dimensions: 100 tons equals 20,000 cubic feet; assumed 40 feet width, 50 feet depth, 100 feet length. Five hundred tons equal 100,000 cubic feet; assumed 50 feet width, 80 feet depth, 250 feet length.

The width has been kept narrow on purpose because of the steep angle of repose found in solid waste materials.

Maximum travel distance: Eqivalent to pit dimensions except for the depth; it is assumed that the height of the hopper in the charging mechanisms requires the addition of 10 feet to the depth values given. Thus:

	100 ton station	500 ton station
bridge span	100 feet	250 feet
trolley span	40 feet	50 feet
hoist	60 feet	90 feet

Average travel distance per round trip: It is assumed that the hopper is located in the middle of the long side of the pit. Furthermore, it is assumed that the distribution of the wastes in the pit is uniform. Thus an average round trip travel distance can be identified as follows: 100 ton station: 40 feet width, 50 feet length, 60 feet depth; 500 ton station: 50 feet width, 125 feet length, 90 feet depth.

Synchronization of movements: Depth, width and length travel occurs simultaneously.

2. Conveyors

Type of equipment: Troughed belt conveyor; 20 degree side angle of belt, 20 degree elevation angle to rail car loading station. Depending upon degree of draft control in the station, it might be necessary to specify covered conveyors.

Density of material: Unprocessed 6 lb/cu.ft; shredded 10 lb/cu.ft.

Belt widths: 72 inches for unprocessed wastes to handle all residential wastes including oversized items; 48 inches for shredded wastes.

Average loading of belt: Unprocessed wastes; 60 inches, 12 inches high. Shredded wastes; 36 inches, 12 inches high.

Speed of belt movement: Unprocessed waste; 13 ton/hr. or, at 6 lb/cu.ft., 4,333 cu.ft./hr. Five feet widths of belt: 866 feet per hour or about 14 feet per minute.

Unprocessed waste: 63 ton/hr. or, at 6 lb/cu.ft., 21,000 cu.ft./hr. Five feet width: 4,200 feet per hour or about 70 feet per minute.

Shredded waste: 13 ton/hr. or, at 10 lb/cu.ft., 2,600 cu.ft./hr. Three feet width of belt: 866 feet per hour or about 14 feet per minute.

Shredded waste: 63 ton/hr. or, at 10 lb/cu.ft., 12,600 cu.ft./hr. Three feet belt width: 4,200 feet per hour or about 70 feet per minute.

3. Hoppers at Rail Car Loading Area

If more than one rail car is used and if the belt movements and associated processing are not to be interrupted, then it is necessary to provide hold-hoppers at the end of the conveyor belts in order to avoid spillage between the rail cars.

Assuming a maximum time period of 10 minutes for the positioning of the rail cars, the size of the hold-hoppers is as follows:

- i. unprocessed waste: 13 tons or 4,333 cu.ft./hr.; about 722 cubic feet.
- ii. unprocessed waste: 63 tons or 21,000 cu.ft./hr.; about 3,500 cubic feet.
- iii. shredded waste: 13 tons or 2,600 cu.ft./hr.; about 433 cubic feet.
- iv. shredded waste: 63 tons or 12,600 cu.ft./hr.; about 2,100 cubic feet.

Hold-hoppers at the rail car loading area are not needed for baled solid waste.

The loading of unprocessed and shredded wastes into the rail cars requires simple dust control provisions.

4. Hopper and distributor to charge the conveyor or processing equipment.

The transfer of the solid wastes from the pit requires machinery to convert the batch loading as delivered by crane into

- a. a steady flow input for unprocessed wastes in order to charge the conveyor at a regular rate of feed, or
- b. a steady flow input for shredded wastes in order to charge the shredder or shredders at a regular rate of feed, or into
- c. a different batch loading for baled wastes in order to charge the press with waste portions controlled by weight.

To ensure continuity of feed operations it was assumed that the receiving hopper would have a capacity twice that of the grab buckets: 10 cubic yard for the 13 tons per hour station and 20 cubic yard for the 63 tons per hour station.

All the distributors would have agitators/controllers to ensure a regular rate of feed as well as proper weighing in the case of compaction processing. The speed of the agitator/controlled device should be variable and be synchronized to the needs of the subsequent process elements.

Some dust control would be needed for the handling of both the unprocessed and processed wastes.

5. Industrial fork lift truck

A small industrial fork lift truck is needed to transport 13 tons per hour of baled waste over a distance of 250 feet and to stack the bales in the rail car.

A slightly larger or medium size industrial fork lift is needed in the 63 ton per hour station to perform the same function.

It is assumed that in each case a round trip would require a maximum of 10 minutes. Thus, the load carrying capacity of the trucks is about two and one-half and 11 tons respectively.

In the overall, the above information demonstrates that material handling does not rank among the "problems" of rail haul transfer stations. An overview of the material handling experience in industry can be taken to support this conclusion.

Estimates of Transfer Station Cost

The information presented in this report on rail-haul transfer stations indicates that a great variety of transfer station layouts and transfer operations is both conceivable and reasonable. Local conditions including the configuration of the site in addition to the selection of the system itself are the major factors which govern the developments of desirable transfer stations.

It is necessary to establish cost estimates in terms of: 1. gross calculations to cover a great variety of possibilities for which the individual cost elements could not be detailed, and in terms of 2. cost examples based upon selected transfer station illustrations established for this study.

Gross Estimates of Rail-Haul Transfer Station Cost

Gross estimates can be made by using ratios of major cost element relationships found in selected industrial operations. Examples of such ratios are found in surveys, annual reports, Government publications, and magazines. The many indivudual inputs may be consolidated as follows:

1. Excluding financing charges, the straight investment cost of processing equipment, material handling equipment, and the building and its appurtenances each account for one-third of the total investment cost.
2. The total annual cost for the building and equipment, the operations excluding labor, and the labor portion of the cost show a relationship of 50:25:25 respectively, and correspondingly.
3. Labor costs make up about 50 percent of the total operating cost, if labor is included in the operating cost data.

The gross estimates of cost are established with the help of these ratios by a two-step procedure. First, known or estimated data available for one or more of the cost elements are inserted into the formula and the data for the unknown cost elements are subsequently calculated.

Second, a brief analysis is made to gauge the reasonableness of the data established for the unknown cost elements, e.g., it is calculated what such estimated cost could buy. It is, of course, wise to use only conservative estimates in any of such calculations made.

Finally, to apply these ratios in a reasonable manner, it is necessary to describe the key conditions of the operations upon which the ratios are based. As a rule, the industrial operations are carried out in terms of one shift per day. Process industries such as refineries operate on a three-shift per day basis and their respective ratios are, of course, not included in the above consolidations.

Furthermore, the service life of buildings and various pieces of equipment varies considerably and the published data reflect furthermore the write-off regulations of the Internal Revenue Service as well as cost accounting practices. Thus, the annual cost ratio, given under input item 2, is a conglomerate of depreciation effects. This ratio is, however, heavily weighed in terms of long-term investments such as buildings and machinery. This suggests that an average depreciation period of 15 to 20 or even 25 years is more appropriate than, for example, a ten-year period.

EXAMPLE 1: Five Hundred Tons per 8-hr/Shift Transfer Station for Baled Solid Wastes

A 500-ton per 8-hr. shift compaction press is conservatively estimated to cost $500,000. Thus, the building and the material handling equipment would cost, using the first ratio, about $500,000 each, and the investment for the total station would run at $1.5 million.

For evaluating how the reasonableness of the material handling investment cost estimate, it might be mentioned that, for example, a 10-ton bridge crane, as used in incinerators, costs about $135,000. For evaluating the building cost estimate, $7.00 is often given as the cost per square foot and 40 to 80 cents as the cost per cubic foot. Thus, $500,000 would buy about 71,500 square feet or 625,000 to 1,250,000 cubic feet of space excluding the cost of land.

To gauge the annual cost for building and equipment it was assumed that interest and financing charges would add a cost equivalent to about 75 percent of the straight depreciation. The depreciation period was assumed to be 20 years for the building, the press, and half of the material handling investment. The depreciation for the other half of the material handling investment was assumed to be ten years. Table 15, Annual Investment Cost indicates the computed annual cost.

At 500 tons per eight-hour shift and 312 working days per year, the annual throughput would amount to 156,000 tons. Thus, the direct investment cost would run 56 cents per ton and if an amount equivalent to 75 percent of these costs, or 42 cents, were added for financing charges, return on investment and other miscellaneous items, the cost for the building and equipment would increase to 98 cents per ton. In turn, using the second ratio given above, the total annual cost is calculated at $1.96 per ton, including about 49 cents per ton for operations and an equal amount for labor.

At 500 tons per shift the labor cost would total in the above example $245 or $30.63 per hour. At an average cost of $5.00 per hour, this would supply about six men, each earning $4.00 per hour or $160 per week if an allowance of 25 percent is made for overhead and fringe benefits. In gauging the reasonableness of the cost for operations, it might be remembered that maintenance and power for the compaction press have been estimated previously at about 20 cents per ton which would leave about 29

TABLE 15

ANNUAL INVESTMENT COST AT A 20-YEAR DEPRECIATION PERIOD EXCLUDING FINANCING CHARGES

Item	Total Amount	Depreciation Period	Annual Cost
Building	$500,000	20 years	$25,000
Press	$500,000	20 years	$25,000
Material Handling, A	$250,000	20 years	$12,500
Material Handling, B	$250,000	10 years	$25,000
	$1,500,000		$87,500

cents per ton or $145 per 8-hr/shift for other direct operating expenditures excluding labor.

Finally, using the third ratio, it can be stated that the press operations, including maintenance, power, and labor, would cost not more than 40 cents per ton. Adding a depreciation cost element of 20 cents per ton and 75 percent of the latter amount for interest and return on investment, the total compaction cost would run generously calculated at about 75 cents per ton. Assuming that an equal amount is spent for the material handling, the transfer station cost would increase to $1.50 per ton, excluding the building. If then the total building and other miscellaneous expenditures were assumed to add a cost of 50 cents per ton, the annual fund available for these items would amount to $78,000 (312 days times $250 per day). In contrast, the annual cost for building investment, financing charges, and return on investment are calculated at only $43,750 within the framework of the present analysis.

In the overall the above information tends to show that it is reasonable to estimate the total transfer station cost at $2.00 to $2.50 per ton. It should be emphasized that these costs refer to a station with a capacity of 500 tons per eight-hour shift and that the size of such an operation requires a reasonable degree of automation. For example, dumping can be controlled by overhead ultrasonic sensing devices and the press operations synchronized with the loading equipment. The process layout as discussed suggests that the operations might in addition to a supervisor, require three people only: a scale master to handle the incoming collection vehicles, a crane operator, and a rail-car loader.

EXAMPLE 2: Five Hundred Tons per 8-hr/Shift Transfer Station for Shredded and Unprocessed Solid Waste

The development of transfer stations for shredded and unprocessed solid wastes received were given limited attention because compaction, as previously mentioned appears to provide an optimum system. This statement, however, should not be taken to indicate that shredded or unprocessed solid waste rail-haul systems are not feasible or applicable.

The previously used approach to gross estimating can also be used to establish some order of magnitude for the cost of transfer stations based upon shredded or unprocessed solid wastes. However, the directly applicable cost elements of size reduction equipment constitutes a very distinct and predominant cost factor. This cost does not appear to lead to economics in the balance of the system. Thus the annual costs of transfer stations for shredded solid wastes are higher than those for compacted solid wastes.

Shredding costs 40 to 60 cents more per ton than compaction. In a very simplistic way the transfer station cost for shredded solid wastes may range from about $2.40 to about $3.10 per ton.

The transfer station cost for unprocessed solid wastes may be gauged in a similar way. The differences between the three systems are primarily the presence of the processing equipment. Thus, for a broad estimate for transfer stations of unprocessed solid wastes we may deduct the annual cost of processing. As a result, the cost of transforming unprocessed solid wastes, within the constraints of transfer stations as indicated in this study, may range from $1.60 to $2.10 per ton.

The Cost Influence of Contract Time and Number of Shifts per Day

The foregoing estimates are based, as indicated, on a 20-year contract time and operations of one shift per day.

To indicate the influence of contract time and changes in the number of shifts per day, it may be assumed, in terms of broad gross estimates, that the operating cost per ton remains constant. Consequently, the influence of the two variables is reflected primarily in the investment cost as projected on an annual basis.

As has been shown previously, the annual portion of the total investment cost amounts to about 98 cents per ton at a 20-year depreciation period and operations of one shift per day. A reduction of the 20-year write-off time to 10 years, would consequently double the annual cost of the investment. As a result the cost per ton at a 10-year write-off period and operations of one shift per day would increase by about 98 cents and the total transfer station cost may be gauged broadly at $3.00 to $3.50 per ton.

Similarly, an increase in the number of shifts per day would result in a greater utilization of the facilities and the annual cost per ton of the investment would be reduced. If everything remains constant, two shifts per day would decrease the annual cost of the investment to one-half and three shifts to one-third of the 98 cent value given above. However, it must be recognized in this context that an increase in the number of shifts necessitates, within the constraints of this analysis, an increase in the size of the pit and adjustments would have to be made.

Cost Estimates for 100-tons/8-hr/Shift Transfer Stations

In making gross estimates for 100-tons per 8-hr/shift transfer stations it is necessary to recognize economics of scale.

The identification of realistic economics of scale is an enormous undertaking where many variables in both technology and possible technical development alternatives are involved. For example, different designs of equipment might have to be established in case the existing equipment does not come in the size and performance category required.

However, the experience of mass production indicates, in principle, that the cost per unit of throughput increases with a decrease in the total amount of throughput. This holds especially true for processing machinery such as presses and, to some degree, for buildings.

In establishing therefore, gross estimates for 100-tons per 8-hr/shift, it was decided to use press cost as an indicator for the variations in the cost per ton. This results, of course, in very rough indicators. However, this approach also tends to provide some margin of safety since the other cost elements appear to not increase as much.

An analysis of presses made for the high-pressure solid-waste compaction program indicated that the compaction might cost in small presses about 50 cents per ton excluding labor. Taking the relationship of 40 cents per ton to 50 cents per ton as the cost escalation factor, it can be estimated that the transfer station cost in 100-ton/8 hr/shift can range from about $2.50 to $3.10 per ton.

Specific Cost Elements

The estimates on transfer station cost were made on a broad basis to cover as many of the individual and local situations as possible.

Within the context of the present study it was, however, possible to identify a number of specific cost elements. These cost elements may, in turn, be used to give validity to the reasonableness of the information given.

The cost elements discussed refer exclusively to items discussed previously under material handling.

The major element is the overhead traveling crane. The same type and size is needed for shredded, unprocessed and baled waste systems and a 500-ton/8 hr/shift station requires high speed operations. The speed of crane operations increases rapidly with a decrease in the load, if electric drives are used. The required crane loads are estimated at only one or two tons per load. The purchase price and installation of such a crane is estimated at $300,000 excluding financing charges. This is the equivalent of about 11 cents per ton at a 20-year write-off period. The total horsepower requirements for the crane should not exceed 100 HP.

The second major cost element is the conveyors. A 72-inch/belt-width conveyor, for unprocessed waste is estimated to cost, including a 20-feet elevation and installation, about $35,000 excluding financing charges. At a 10-year write-off period this would amount to less than 3 cents per ton. The horsepower requirements should not exceed 15 HP.

The conveyor for shredded solid wastes is estimated to cost $25,000. In contrast, a 12-ton fork lift truck is estimated to cost $15,000.

The third major cost element is the process feeding equipment. The input for high-pressure compaction requires a rough control of the feed by weight only. Such equipment is not now available. However, preliminary estimates, for a 500-ton station placed the investment cost in the neighborhood of $25,000, excluding financing charges.

In the overall, the information given above on some transfer station elements suggests, that the economic feasibility of transfer stations can be assumed and estimated at $2.00 to $2.50 per ton.

CHAPTER 3

TRANSPORT OF SOLID WASTES

BASIC CONSIDERATIONS

Transport environment, time, quality of movement, volume, and weight are basic considerations in the transport of materials. Transport environment and time are evaluated in terms of public health, volume and weight of material in terms of transport cost. The quality of the movement—the ride—is not considered significant in the transport of loose, shredded, or baled solid wastes.

PUBLIC HEALTH ASPECTS

The public health aspects of long-haul transport of solid wastes may be differentiated from short distance movements of solid wastes principally in terms of time effects. Solid wastes normally are contained in the transporting vehicle several hours, rarely longer than 24 hours. In contrast, long distance transport might retain the wastes for longer time periods depending upon the mode of transport as well as the system configuration and scheduling.

The principal environmental requirements for shipping solid wastes should be such that the materials are not exposed:

1. to rain regardless of whether they are unprocessed, shredded, or baled;
2. to prolonged periods of freezing if the materials are unprocessed or shredded;
3. directly to the wind; and
4. to high temperature.

In addition, unprocessed wastes require use of watertight rail cars to avoid drainage of moisture from the refuse. Shredding and baling, on the other hand, appear to remove or redistribute a significant portion of the excess moisture that otherwise might be released during transport; thus, watertight cars are not required. All cars should, of course, be designed to facilitate cleaning.

Following the rules of good practice for the operation of incinerators, all wastes should be disposed of within seven days of collection.

TRANSPORT REQUIREMENTS

Transport vehicle load carrying capability is keyed to weight and volume relationships. The relative importance of volume or weight depends upon the density of the materials shipped. Volume factors are important in the shipment of uncompacted household refuse; weight factors are important in the shipment of high density materials such as heavy metals.

The relationship between volume and weight of solid wastes at various densities is graphically presented in Figure 14, Relationship Between Volume and Weight at Various Solid Wastes Densities. The straight-line relationship indicates, for example, that the volume of material at 10 lb/cu. ft. is six times that of material at 60 lb/cu. ft.

RAIL TRANSPORT

Railroads represent the leading mode of transportation for the movement of freight. Motor trucks are second, pipelines third, and barges fourth. Freight, in this statistic, includes solid as well as liquid materials, which explains the relatively high share of pipeline transport.

The rail data presented throughout this report are derived from the operating experience of Class I line-haul railways. These include the carriers having annual revenues of $5 million or more. Class I line-haul operating companies:

1. represent only 12 percent of the companies connected directly with the execution of rail transport;
2. operate, however, about 96 percent of the total miles of main track, including trackage rights;
3. own about 93 percent of all the locomotives and about 98 percent of all the freight train cars in service;
4. employ about 93 percent of all railroad personnel;
5. carry about 95 percent of the total freight tonnages;
6. account for about 99 percent of the freight revenue ton-miles;
7. earn about 96 percent of the total railway operating revenue, and
8. represent about 95 percent of the total capital stock of the industry.

Thus, Class I railroad transportation data can be used to develop realistic solid-waste rail-haul configurations in the eastern territory of the ICC data. Moreover, these data are based on actual working experience and therefore include existing labor contracts and a multitude of different operating regulations.

To obtain a perspective of the ability of the rail network to serve an area, a comparison of the length of the rail network related to the total area and/or

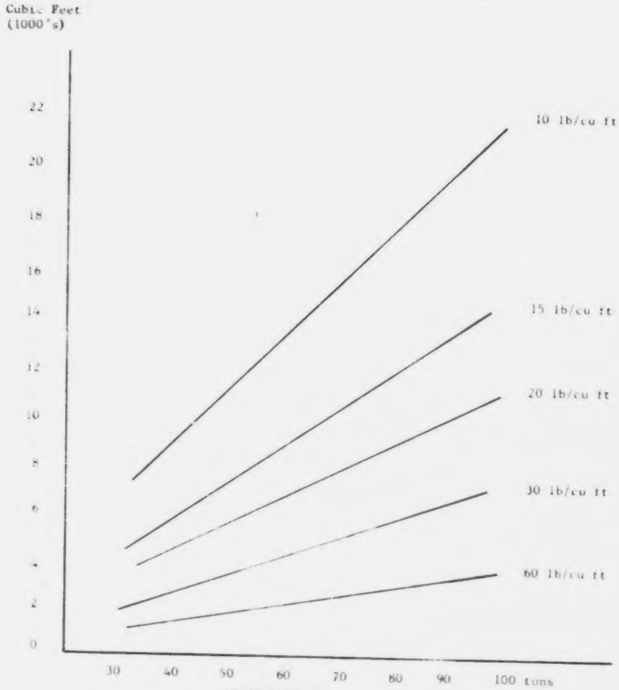


FIGURE 14

THE RELATIONSHIP BETWEEN VOLUME AND WEIGHT AT VARIOUS SOLID WASTE DENSITIES

TABLE 16

RAILROAD MILEAGE OF THE CONTIGUOUS UNITED STATES (by State)

State	Total Miles of Railroad	Number of Square Miles per Mile of Road	Number of People per Mile of Road (1960 Population)
United States Total	212,059	16.74	932
Alabama	4,624	11.16	707
Arizona	2,053	55.51	634
Arkansas	3,725	14.26	480
California	7,516	21.11	2,091
Colorado	3,775	27.62	465
Connecticut	773	6.48	3,279
Delaware	293	7.02	1,522
Florida	4,478	12.79	608
Georgia	5,567	10.58	708
Idaho	2,677	31.21	249
Illinois	10,996	5.13	917
Indiana	6,525	5.56	715
Iowa	8,437	6.67	327
Kansas	8,059	10.21	270
Kentucky	3,525	11.46	862
Louisiana	3,899	12.44	835
Maine	1,691	19.64	573
Maryland	1,135	9.32	2,732
Massachusetts	1,573	5.14	3,274
Michigan	6,461	9.01	1,211
Minnesota	8,037	10.46	425
Mississippi	3,632	13.14	600
Missouri	6,513	10.70	663
Montana	4,939	29.79	137
Nebraska	5,574	13.85	253
Nevada	1,635	67.61	174
New Hampshire	817	11.39	743
New Jersey	1,853	4.44	3,274
New Mexico	2,190	55.56	434
New York	5,858	8.46	2,865
North Carolina	4,270	12.34	1,067
North Dakota	5,195	13.60	122
Ohio	8,139	5.06	1,193
Oklahoma	5,604	12.48	415
Oregon	3,161	30.68	560
Pennsylvania	8,693	5.18	1,302
Rhode Island	157	7.73	5,471
South Carolina	3,261	9.52	731
South Dakota	3,910	19.71	174
Tennessee	3,339	12.65	1,068
Texas	14,277	18.73	671
Utah	1,725	49.23	517
Vermont	719	13.36	542
Virginia	4,085	9.99	971
Washington	4,955	13.76	576
West Virginia	2,582	6.75	519
Wisconsin	6,133	9.16	644
Wyoming	1,848	52.98	179
District of Columbia	31	2.23	24,645

Source: Data developed from information published by the Interstate Commerce Commission and U. S. Bureau of the Census the population is helpful. The lower the number of square miles per mile of road, and the higher the population density per mile of road, the greater the potential benefit.

The rail network mileage, the ratios of square miles, and the number of people per miles of railroad in each state are shown in Table 16. The data indicate, for example, that New Jersey with one mile of track for each 4.44 square miles of area and 3,274 population may have a high potential for the use of rail-haul.

CONSIDERATION OF TYPE OF RAILROAD CARS

Either existing or specially designed freight cars could be used for the rail-haul of solid wastes. The decision as to which type of car to use will depend upon the form in which the solid wastes are to be shipped, e.g., unprocessed, compacted, or in stable bales.

Existing Freight Train Cars

A variety of freight train cars are used to accommodate the needs of the various shippers. However, general purpose cars are prevalent. Thus, if special railroad cars must be designed they should be suitable for a variety of uses in order to achieve maximum equipment utilization should solid-waste rail-haul be abandoned.

In 1964, there were about 1,534,000 freight train cars in service. About 1,504,000 of these cars are owned by the Class I railroads. A breakdown of these freight train cars by class is presented in Table 17, Type of Freight Train Cars Owned by Class I Railroads.

TABLE 17

TYPE OF FREIGHT TRAIN CARS OWNED BY CLASS I RAILROADS

Boxcars, general service	515,123	34.1
Boxcars, special service	81,220	5.3
Flatcars	48,257	5.3
Stock cars	22,445	1.5
Gondola cars	222,897	15.1
Hopper cars, open top	431,791	28.7
Hopper cars, covered	81,168	5.3
Refrigerator cars	36,922	2.4
Rack cars	41,075	2.7
Tank cars	5,157	0.4
Other freight train cars	2,330	0.2
Caboose cars	15,549	1.0
TOTAL freight cars	1,503,934	100.0

Source: Interstate Commerce Commission, 1967 Transport Statistics in the United States, Year ended December 31, 1964.

Table 17 indicates that general service boxcars, open hopper cars, and gondolas represent more than three-fourths of the freight cars in use. No other type makes up as much as six percent of the total.

Since solid wastes can be processed in a way to suit many different types of cars, it is appropriate to review the cost of various types of cars. The average cost of new freight train cars by type in 1969 is given in Table 18, Average Purchase Price of Freight Train Cars.

The advantages and limitations of existing cars and their implications for the transport of solid wastes are:

1. Boxcars

According to its name, the boxcar is enclosed on all sides and has a roof. One or more doors are placed on each of the long sides of the car. The boxcar is generally used for shipments which must be protected from the weather. As a rule, shipments consist of boxed, crated, or bagged materials or products which can be readily handled in unitized loads as, for example, packages stacked on pallets and moved by a forklift truck.

For transport of solid wastes, boxcars would provide protection from the undesirable weather effects. However, they are not suitable for loose or shredded solid wastes because of the difficulty of loading and unloading. On the other hand, boxcars are suitable for compacted wastes which can be loaded and unloaded in the same manner as bagged or boxed materials. One version of the boxcar is the "All Door" car in which the long sides of the car consist exclusively of doors to facilitate loading and unloading. Figure 15 is a sketch of an All-Door Box Car being unloaded by a mobile loader.

2. Flatcars

Flatcars consist of a car floor without an upper housing or body. Some flatcars have bulkheads. Those with movable bulkheads may be suitable for the transport of baled solid wastes, if the bales are prepared in such a manner that covers are not required. Flat cars can also be used if the wastes are containerized.

3. Gondola Cars

Gondola cars come equipped with sides and ends but, as a rule, without tops. The car floor is approximately level and may be provided with bottom doors and/or drop ends. The sides of the car may be high or low. Several types of removable covers are also available to protect the shipment from the weather. Covers are designed not to interfere with

TABLE 18
AVERAGE PURCHASE PRICE OF FREIGHT TRAIN CARS

Class of Cars	Number of Units	Average Cost per Unit (dollars)
Boxcars, General Service, Unequipped[1]	6,588	$11,700
Boxcars, General Service, Equipped[1]	11,179	17,500
Boxcars, Special Service	633	27,300
Flatcars, General Service	456	13,800
Flatcars, Special Service	2,298	18,200
Flatcars, Trailers on	—	16,500
Gondolas, General Service	1,863	12,800
Gondolas, Special Service	1,314	15,100
Hoppers, Open Top, General Service	6,262	12,500
Hoppers, Open Top, Special Service	100	17,900
Hoppers, Covered	4,987	15,200
Refrigerator, (Other than Meat)	1,200	30,600
Autorack	283	19,200
Tank Cars		

Transport Statistics in the United States (1969), Interstate Commerce Commission—Costs rounded to nearest 100; prices reported are those at the time of contract-paid in 1969.

[1] As designated by ICC

loading or unloading operations. Figure 16 is a sketch of a 100-ton side-dump gondola.

With a cover, gondolas could be used to transport processed, particularly baled, solid wastes. The loading and unloading process would vary dependent upon the condition in which the materials are shipped. Several types of loading equipment are available, including car dumpers ($200,000 to $500,000—excluding the foundation and pit), and mobile gantry cranes. Rotary car dumpers would seldom be economically justified unless the annual volume exceeded two million tons of refuse at the destination point. Mobile gantry cranes are available in capacities of 1- to 50-ton lifts, and with spans of up to 30 feet. Unless the gondolas were watertight, they would not generally be suitable for transport of unprocessed solid wastes.

4. Hopper Cars

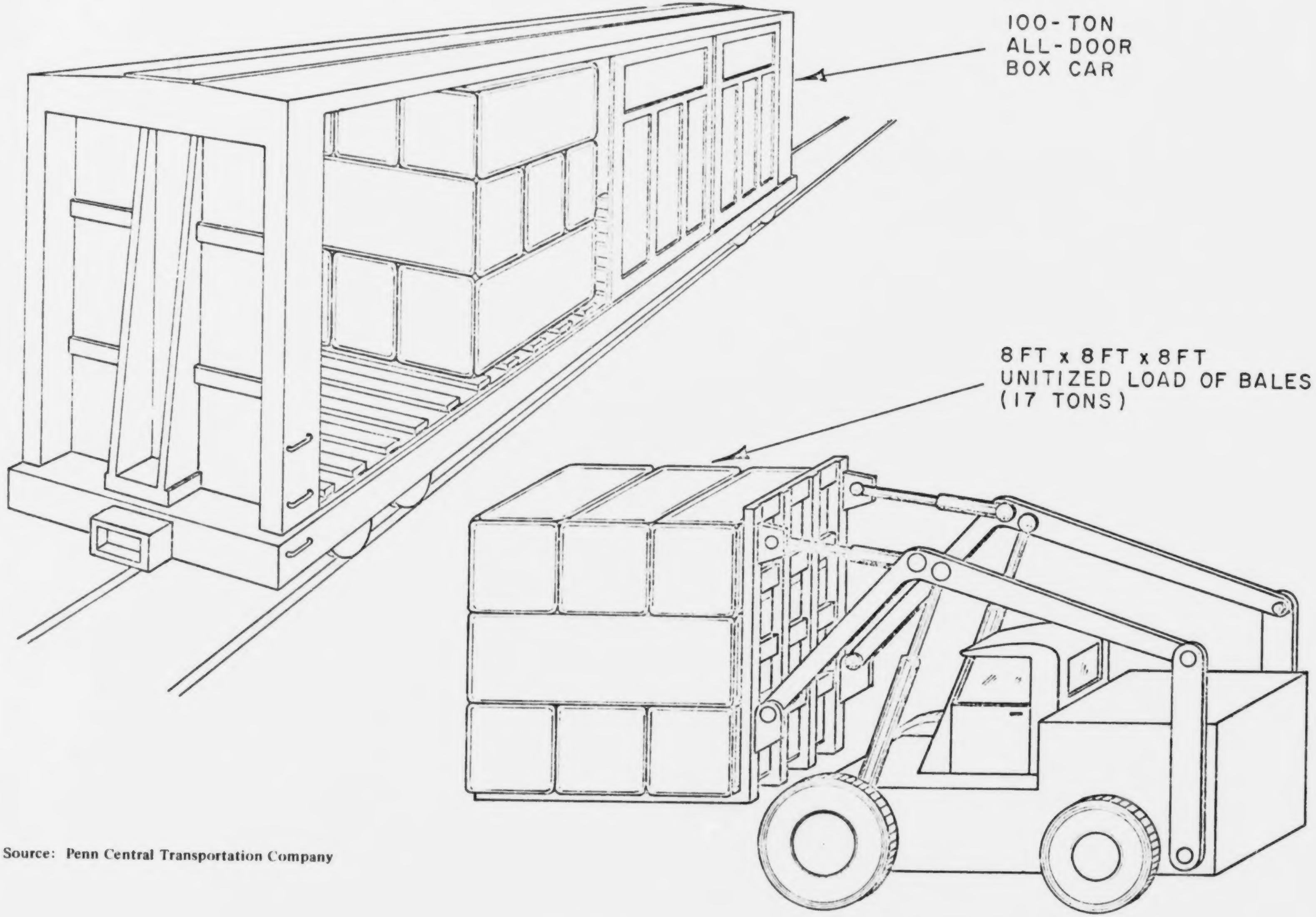
Hopper cars are designed to discharge their loads by gravity through hopper doors built into the floor. Thus, they have floor sections and/or sides which slope to the one or more bottom openings in each car. Hopper cars may be either uncovered or have a permanent roof equipped with hatches. Figure 17 is a sketch of a standard hopper car and a 100-ton "rapid discharge" hopper car.

Hopper cars are used for the transport of relatively small size, free-flowing materials. Large, standard size hopper gates only measure approximately 25 by 48 inches.

Unprocessed residential solid wastes could be readily loaded into open-top hopper cars. Serious difficulties would occur, however, in the unloading of the car due to both the matting and clinging properties of the materials and the presence of oversized items. These problems might be alleviated if the wastes were shredded and kept dry, preventing paper from absorbing moisture from the atmosphere.

The unloading problems also might be averted if the refuse were compacted into briquettes of the size of baseballs or footballs. In this way a relatively free flow might occur. The cars would require covers. Hopper cars would need large discharge openings, preferably 40 by 100 inches; steep, sloped angles, and stainless steel liners.

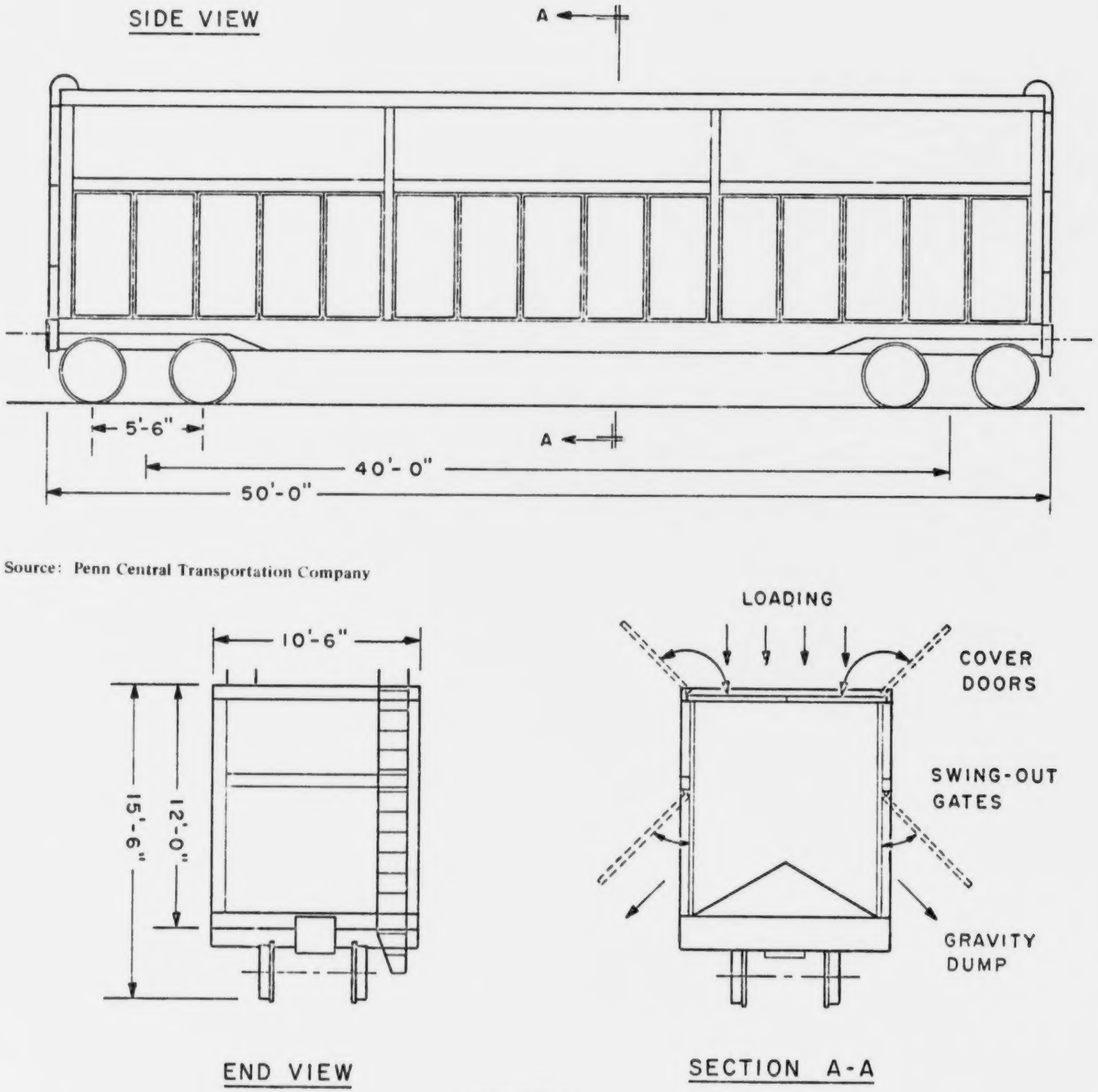
Existing *covered hopper* cars do not appear to be suitable for the hauling of solid wastes since they are


100-TON
ALL-DOOR
BOX CAR
8 FT x 8 FT x 8 FT
UNITIZED LOAD OF BALES
(17 TONS)

Source: Penn Central Transportation Company

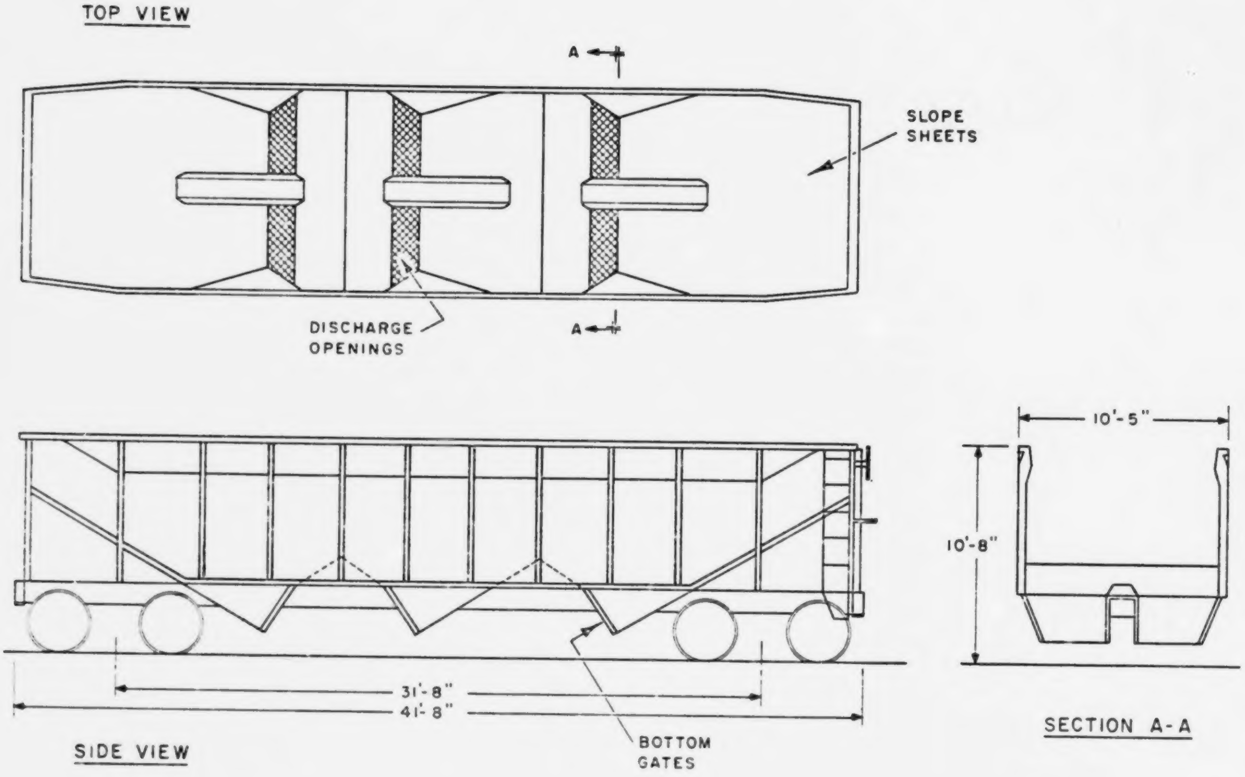
FIGURE 15

ALL-DOOR BOX CAR AND MOBILE LOADER


SIDE VIEW
A
A
5'-6"
40'-0"
50'-0"
END VIEW
10'-6"
12'-0"
15'-6"
SECTION A-A
LOADING
COVER DOORS
SWING-OUT GATES
GRAVITY DUMP

Source: Penn Central Transportation Company

FIGURE 16
100-TON SIDE-DUMP GONDOLA


TOP VIEW
A
SLOPE SHEETS
DISCHARGE OPENINGS
A
10'-5"
10'-8"
31'-8"
41'-8"
SIDE VIEW
BOTTOM GATES
SECTION A-A

Source: Penn Central Transportation Company

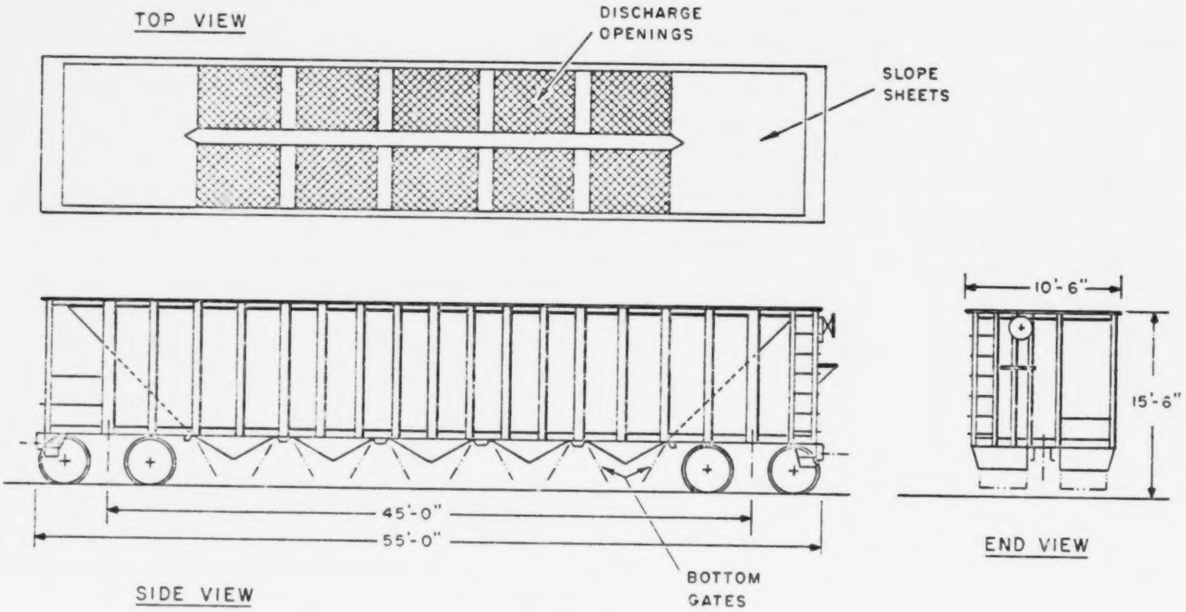

TOP VIEW
DISCHARGE OPENINGS
SLOPE SHEETS
10'-6"
15'-6"
45'-0"
55'-0"
END VIEW
BOTTOM GATES
SIDE VIEW

FIGURE 17

STANDARD HOPPER CAR & 100-TON RAPID-DISCHARGE HOPPER CAR

designed primarily for the shipment of powdered or granular, free-flowing materials.

5. Tank Cars

Tank cars have only relatively small loading and unloading openings. Thus, they could be used only if the wastes were ground to a sufficiently small size to pass the entry and exit ports. Unloading by air or liquid pressure might lead to problems of settling, clogging, and varying density of the wastes.

A review of the preceding discussion suggest that:

- unprocessed, loose, and shredded solid waste should be shipped primarily in covered gondola cars, containerized waste in flatcars or boxcars; and that
- baled solid wastes should be shipped primarily in covered gondolas and boxcars; and, if covered and suitably packaged, on flatcars.

Thus, the boxcar, the gondola, and the flatcar are the primary rail car choices to be considered in the development of the optimum solid-waste rail-haul system.

RAILROAD FREIGHT CARS–VOLUME/NET LOAD RELATIONSHIPS

In the transport of solid wastes by existing freight train cars, it is important to consider the relationship of volume and net load carrying capability. For example, a doubling of the net load per car may reduce car investment by half and save on other transportation costs as well.

The theoretical limits of the volume/net load relationship are given in Table 19, Limits of the Volume/Net Load Relationship for Various Freight Cars. The data refer to the most common types of cars. However, to add perspective, information on Hi-Cube cars is also included, although the number of such cars in service is small. Hi-Cube cars are considered specialized cars which are used mainly for the shipment of packaged high volume/low weight merchandise.

In reviewing Table 19, Limits of the Volume/Net Load Relationship for Various Freight Cars, it must be recognized that the information is based upon the "maximum load limit" which is not identical with the nominal or nameplate carrying capacity given for the cars. The "maximum load limit" exceeds, in most cases, the nominal carrying capacity. However, as indicated in the "Car and Locomotive Cyclopedia" for the Hi-Cube boxcar, the maximum load limit may also be less–sometimes as much as 25 percent to 30 percent–than the nominal capacity given.

The theoretical load density limits do not take into account the practical loading patterns that might be achieved. Practical loading patterns might reduce the available car volume capacity by at least 15 to 20 percent. This, in turn, would increase the individual pounds per cubic foot values given by a like amount. Furthermore, due to loading constraints associated with access through doors and working in an enclosed space, the usable space in boxcars may be considerably less than that indicated unless "All-Door" cars are used.

Thus, the information in Table 19 suggests that a cargo density of 50 to 80 lb/cu. ft. would be optimal with respect to the use of most existing freight train cars. A material density of this order can only be achieved by high-pressure compaction which therefore was made the subject of the first demonstration project resulting from this study.

RAIL CAR ECONOMICS

Rail car economics depend on acquisition and utilization cost. Car utilization, in turn, depends upon the net load carried, e.g., density of materials, and the number of revenue producing trips made during a given time period. Only boxcars, gondolas, and flat cars were analyzed.

1. Rail Car Acquisition Cost

Cost of rail cars is given in Table 20, Range of Standard Rail Freight Car Purchase Price by Load Carrying Capacity. The price of a 100-ton car could vary from $12,500 to $22,200 depending on type and number of units purchased. Forty-foot gondolas and flat cars as well as cars with load limits of 50 tons are not shown in the table because such cars are no longer considered production line items. There is a trend toward the 100-ton and even the 125-ton rail car because of the advantageous economics. However, track conditions of the rail lines to be used may dictate the use of lower capacity cars.

Although the rail car acquisition cost will normally be borne by the railroad and has been discussed here in order to determine the applicable rates which will be charged to a user, the using agency would, most likely, purchase any containers that would be utilized. An 8-by 8-by 20-foot container costs about $6,000 and an 8-by 8-by 40-foot container about $10,000. These standard dimensions suggest that either 68- or 89-foot flat cars be used and that $18,000 (three 20-foot containers) and $20,000 (two 40-foot containers) be considered as a reasonable purchase price.

TABLE 19

LIMITS OF THE VOLUME/NET LOAD RELATIONSHIP FOR VARIOUS FREIGHT CARS

Type of Car (Nominal Capacity)	Special Features	Capacity (Cu. ft.)	Maximum Load Limit (Lbs.)	Lbs./ Cu. ft.
Gondola Cars				
50 ton	low sides	1,153	129,000	112
50 ton	all steel, drop bottom	1,948	100,000	51
50 ton	fixed-end, drop doors	1,948	100,000	51
70 ton	fixed-end	1,700	151,000	89
70 ton	fixed-end	1,995	158,200	79
70 ton	fixed-end	1,995	162,600	82
70 ton	mill type, drop ends	1,776	144,800	82
70 ton	mill type, drop ends	1,775	141,400	80
70 ton	wood floor, ends, & sides (for sulfur load only)	1,573	158,700	101
70 ton	drop bottom for handling coke	3,125	153,600	49
70 ton	fixed-end, 16 ft. drop doors	2,410	140,000	58
70 ton	solid bottom, movable bulkheads	2,868	143,000	50
70 ton	covered steel floor	3,520	146,500	42
70 ton	covered, bulkheads	2,324	140,000	60
100 ton	non-railroad owned	4,300	250,800	58
Hopper Cars				
50 ton	open top, double hopper	2,160	135,200	63
70 ton	open top, triple hopper	2,460	168,200	68
70 ton	open top, triple hopper	3,030	164,100	54
70 ton	open top, triple hopper	2,700	157,000	58
80 ton	open top, triple hopper	2,960	166,100	56
80 ton	open top, triple hopper	2,821	166,300	59
90 ton	open top, triple hopper	2,868	202,600	71
90 ton	open top, double hopper	2,100	191,900	91
95 ton	open top, triple hopper	3,418	204,300	60
100 ton	automatic dumping, open top	3,600	200,000	56
100 ton	open top, triple hopper	3,418	201,300	59
100 ton	open top, triple hopper	3,366	200,000	59
100 ton	open top, quadruple hopper	3,483	200,000	57
100 ton	open top, sextuple hopper	4,003	195,200	49
100 ton	wood chip car, sextuple hopper	7,000	200,000	29
90 ton	wood chip car, sextuple hopper	7,000	188,500	27
70 ton	wood chip car	5,850	143,500	25

Type of Car (Nominal Capacity)	Special Features	Capacity (Cu. ft.)	Maximum Load Limit (Lbs.)	Lbs./ Cu.ft.
Boxcars				
50 ton	15 foot door	4,888	92,900	19
50 ton	8 foot door	3,908	100,000	26
70 ton	16 foot double doors	4,932	152,500	31
70 ton	16 foot double doors	4,884	156,400	32
70 ton	16 foot double doors	4,952	155,300	31
80 ton	16 foot double doors	6,013	176,000	29
90 ton	single door	6,146	180,000	29
100 ton	16 foot double doors	5,980	181,400	30
70 ton	hi-cube for low density packaged goods	10,000	105,500	11
70 ton	hi-cube two 16 foot double doors	10,000	102,100	10
70 ton	hi-cube for low density auto parts	10,000	110,400	11

Flat Cars	Approximate Area (Sq. Ft.)	Load Limit (Lbs.)
50 ton	53 x 10 = 530	114,800
50 ton	45 x 10 = 450	111,300
70 ton	56 x 9 = 504	152,700
70 ton	60 x 9 = 540	148,800
70 ton	60 x 10 = 600	150,500
70 ton	53 x 10 = 530	170,400
80 ton	60 x 10 = 600	183,500
90 ton	58 x 9 = 522	184,400

Source: Manufacturers and Railroad Data, Car and Locomotive Cyclopedia, 1966, (Simmons-Boardman Publication)

TABLE 20

RANGE OF STANDARD RAIL FREIGHT CAR PURCHASE PRICE BY LOAD CARRYING CAPACITY

Type and Length of Car	Load Carrying Capacity 70 tons (dollars)*	100 tons (dollars)*
Box Cars		
40.6 feet	11,500 - 14,200	12,500 - 15,200
50.6	13,800 - 15,000	14,800 - 16,000
60.9	19,000 - 20,700	20,000 - 22,200
50.6 (All-Door)	15,000 - 16,000	16,000 - 17,000
Gondola Cars		
Low side 3'6"		
52.6 feet	13,200 - 14,200	14,200 - 15,700
65.6	15,700 - 17,300	16,700 - 18,800
Flat Cars		
50 feet	11,000	12,000
60	15,000	16,500
68	17,250	18,250
89	20,600	21,600

Sources: Various railroads and railcar manufacturers.

* The low values of the purchase price range reflect volume discounts which are attainable through orders involving several hundred cars.

The data in Table 20 reveal an interesting relationship between purchase price and length of car. For example, an increase of 20 percent in the length of a 50-foot car is, for box and flat cars, accompanied by an increase of approximately 40 percent in cost. Thus, from a car investment point of view, compact cars should be given careful consideration in the selection of desirable density targets. In contrast, the data in Table 20 indicate that an increase in the load carrying capacity is relatively inexpensive. The purchase price increases, as a rule, by only $1,000 with an increase in the load carrying capacity from 70 to 100 tons, i.e. about $33 per ton of capacity increase.

It is customary to transform the purchase and acquisition cost into annual cost in order to make these data ready for utilization analyses. This requires consideration of the service life which, based upon Internal Revenue Service regulations, is commonly estimated to range between 10 and 15 years.

The service life, however, represents only one factor in the determination of the annual cost. Additional factors include interest, return on investment for the owner of the car, and maintenance. To estimate total car investment it appears necessary to increase the annual investment cost by perhaps 100 percent in order to make the necessary allowances.

The annual cost of rail cars for the rail-haul of solid wastes has been calculated and is shown in Table 21, Annual Cost of Owning Rail Cars. Conservative data are based on high values given in the range of purchase prices in Table 19 and a 10-year depreciation period was used.

In evaluating the data in Table 21, it must be recognized that the "cost per ton of load carrying capacity" indicates—in terms of annual cost—the cost needed just to establish and maintain the capacity given. Transport costs are not included. The latter costs are determined by the capacity utilization, i.e., the density of the materials and number of trips per year.

TABLE 21

ANNUAL COST OF OWNING RAIL CARS (10-YEAR SERVICE LIFE, 100 PERCENT ALLOWANCE FOR INTEREST, RETURN OF INVESTMENT, MAINTENANCE, ETC.)

Type and Length of Car	Estimated Purchase Price	Total Annual Owning Cost	Cost per Ton of Design Load Carrying Capacity
Box Cars - 70 Tons			
50.6 feet	$15,000	$3,000	$ 43 ($42.85)
60.9 feet	20,700	4,140	59 ($59.14)
50.6 feet (All-Door)	16,000	3,200	46 ($45.71)
Box Cars - 100 Tons			
50.6 feet	16,000	3,200	32
60.9 feet	22,200	4,400	44 ($44.40)
50.6 feet (All-Door)	17,000	3,400	34
Gondola Cars - 70 Tons Low side 3'6"			
52.6 feet	14,200	2,840	41 ($40.57)
65.6 feet	17,300	3,460	49 ($49.14)
Gondola Cars - 100 Tons Low side 3'6"			
52.6 feet	15,700	3,140	31 ($31.40)
65.6 feet	18,800	3,760	38 ($37.60)
Flat Cars - 70 Tons			
68 feet (3 containers at 20 feet)	35,250	7,050	101 ($100.71)
89 feet (2 containers at 40 feet)	40,600	8,120	116
Flat Cars - 100 Tons			
68 feet (3 containers at 20 feet)	36,250	7,250	72 ($72.50)
89 feet (2 containers at 40 feet)	41,600	8,320	83 ($83.20)

TABLE 22
RAIL CAR UTILIZATION – BY DENSITY

Type and Length of Car	Approx. Theoretical Cubic Capacity (cubic feet)	Approx. Practical Cubic Capacity (cubic feet)	Tons of Solid Waste Per Car at Material Shipment Density of			
			10 lbs.	20 lbs. (cubic feet)	30 lbs.	60 lbs.
Box Cars						
50.6 feet	5,000	4,000	20.0	40.0	60.0	120.0
60.9 feet	6,000	4,800	24.0	48.0	72.0	144.0
50.6 feet (All-Door)	5,000	4,000	20.0	40.0	60.0	120.0
Gondola Cars (low side)						
52.6 feet	1,780	1,600	8.0	16.0	24.0	48.0
65.6 feet	2,220	2,000	10.0	20.0	30.0	60.0
Flat Cars						
68 feet (3 containers at 20 feet)	3,840	3,500	17.5	35.0	52.5	105.0
89 feet (2 containers at 40 feet)	5,120	4,600	23.0	46.0	69.0	138.0

Source: Basic data on freight car dimensions obtained from various railroads, rail car manufacturers, and car manufacturers, and "Car and Locomotive Cyclopedia 1966," Simmons-Boardman Publishing Corporation, New York.

2. Capacity Utilization: Density of Solid Waste Materials

A given rail car provides a set volumetric capacity which can be filled up to the limits of the set load (weight) carrying capacity with the materials to be transported. High density materials will not require all the space available. Light materials will fill up all the space available but not require all the load (weight) carrying capacity.

The influence of density on car utilization is given in Table 22, Rail Car Utilization by Density. Existing loading experience has been taken into consideration. This requires a reduction in theoretically available volume for box cars of about 20 percent; and for containers and gondolas, about 10 percent.

Table 23, Annual Cost of Owning Rail Cars At Selected Densities, correlates economics and car utilization by density. It indicates that high-pressure baled solid wastes provide, in terms of car economics, an advantage even in cases where the total volume of the available space is not used.

3. Capacity Utilization: Number of Trips Per Year

The data in Table 19 indicated the cost per ton that would be incurred if the car would make only one load trip per year. This, of course, does not occur in normal railroad operations but is included as a basic point of reference.

In conventional train service, the freight car moves in trains about 10 percent of the time. About 40 percent of the time it is standing in customer yards and the remaining 50 percent is spent in railroad yards. As a result of this waste of time, a rail car travels an average of only 52 miles per day.

In contrast, unit trains move from 50 percent to 90 percent of the total time, averaging 75 percent. Unit trains move from 500 to 700 miles per day. Fixed equipment costs, therefore, are spread over five to nine times more ton miles than in conventional service.

In general, waiting at the transfer station, length

TABLE 23

ANNUAL COST OF OWNING RAIL CARS AT SELECTED DENSITIES (IN DOLLARS PER TON CARRYING CAPACITY)

Type and Length of Car	Total Annual Owning Cost	Cost per Ton of Solid Waste Carrying Capacity at Material Shipment Density of			
	(dollars)	10 lb. cu.ft.	20 lb cu.ft.	30 lb. cu.ft.	60 lb. cu.ft.
Box Cars - 70 Tons					
50.6 feet	$3,000	$150	$ 75	$ 50	N.A.
60.9 feet	4,140	172	86	59 (1)	N.A.
50.6 feet (All-Door)	3,200	N.A.	N.A.	54 (2)	N.A.
Box Cars - 100 Tons					
50.6 feet	$3,200	$160	$ 80	$ 53	$32 (1)
60.9 feet	4,440	185	93	62	44 (1)
50.6 feet (All-Door)	3,400	N.A.	N.A.	57 (2)	34
Gondola Cars - 70 Tons (low side)					
52.6 feet	$2,840	$335	$178	$118	$59
65.6 feet	3,460	346	173	116	58
Flat Cars - 70 Tons					
68 feet (3 containers at 20 feet)	$7,050	$403	$207	$134	N.A.
89 feet (2 containers at 40 feet)	8,120	353	174	118	N.A.
Flat Cars - 100 Tons					
68 feet (3 containers at 20 feet)	$7,250	$414	$207	$138	$72 (1)
89 feet (2 containers at 40 feet)	8,320	362	181	121	83 (1)

N.A. = not applicable either because of material characteristics or too great a load difference, e.g., between 70 and 100 tons.

(1) Cost per ton of Design Load Carrying Capacity (Table 20) taken: it is assumed that the load would be reduced to not exceed the load limit given in the car designation. However, "overloading" does occur in real-life operations.

(2) Assumption is made that solid waste is baled at low pressure and strapped. (Strapping costs are, at that density, about $0.60 per ton).

of haul, travel speed, and turn-around time will determine whether a given trip can be made every day or not. If a car can be used productively only every other day, then twice as much equipment would be needed to haul a given daily tonnage.

Considering intrastate solid-waste rail-haul networks, travel distance as a rule would not exceed 100 to 150 miles one way as determined from rail network analyses.

The trains' total direct travel time would require typically three hours – at most, 10. This would leave from 14 to 21 hours for train assembly, if more than one transfer station is operated, and loading and unloading operations. Thus it is possible that a rail car could be used daily.

The effects of variations in the number of trips made per year are shown in Table 24, Annual Cost of Owning Rail Cars At Selected Utilization Rates. The table gives data for 100, 200, and 300 trips per year at densities of 20 and 60 lb/cu.ft. The densities were selected to indicate best average conditions, on a country-wide basis, for unprocessed or shredded solid waste (540 lb/cu.yd.) versus just average conditions for high-pressure baled solid wastes.

The type of car entries in Table 24 were selected in terms of the minimum cost shown in Table 23 for the respective car type. At 300 trips per year the minimum cost for 20 lb/cu.ft. density is 25 cents per ton. The minimum cost at 60 lb/cu.ft. is 12 cents per ton. Thus with a 300,000 tons throughput per year the cost differential in just the car owning and maintenance cost could amount to $39,000 per year.

The density implications are even more important if the car makes only 100 trips per year. In this case, the cost differential would amount, on the same types of cars, to 41 cents per ton. Again at 300,000 tons of throughput per year, the cost differential amounts to $123,000 per year.

Similar calculations can be made for the flat car plus container analyses as well as the 70-ton flat car versus the 70-ton gondola analysis. It should also be noted that rail car leasing costs in 1970 were quoted to range from 24 cents to 35 cents per ton for the shipment of solid wastes.

In the overall it should be stated that the rail car analysis take present conditions fully into account.

For example, it is well recognized that shortages in rail car availability occur regularly each year. Therefore, the solid waste rail car analyses were based on both the acquisition (and outside financing) of new rail cars and on dedicated service. The purchase of new rail cars for solid waste hauls and the dedication of such cars to that service would make rail haul independent of the presently available rail car stock.

If presently rolling rail cars are dedicated to rail haul, then this would reduce the number of cars (many of them idle much of the time) available for other purposes. Correspondingly, it would increase the car shortages occurring regularly at specific periods each year.

However, this is nothing new and considering the total number of cars, the initial demand for solid waste cars is insignificant. In principle, the railroads have always met their contractual obligations and rail haul is proposed to operate on the basis of contractual arrangements. The car shortages occur with respect to peak demand (once-a-year) customers, e.g., grain shippers, and not with respect to regular, year-round shippers.

SOLID WASTE TRAINS

There are four basic train-type alternatives which are potentially applicable to a solid-waste rail-haul system. Choice of any one would depend on the specific set of circumstances which exist in the local or regional network, e.g., the waste volume, the number of originating points, desired schedules and turn-around requirements.

1. Regular Freight Train Service

In regular freight train service one or more carloads of solid waste would be handled like carloads of any other commodity. Cars would be attached to a regularly scheduled freight train. This approach offers considerable flexibility in operations but poses the restriction on the railroad that the refuse car be not subject to excessive delays in transit. This alternative would not serve all communities since some have infrequent freight service. In addition, the selection of suitable disposal sites would be restricted to points on routes where freight trains can drop off the refuse cars. This, in turn, would require provision for local switching service, adding to the cost.

Refuse cars used in such service might have to be dedicated exclusively to the transport of solid wastes and might not be available for any other shipment. This requirement is entirely compatible with normal rail operations and does not impose something new into railroad practice. The exclusive dedication of cars to the transport of solid waste will, of course, affect the utilization of the equipment. Dedication of freight cars in the context of regular freight train service is likely to prevent a maximum utilization of the equipment and thus increase the system cost.

TABLE 24

ANNUAL COST OF OWNING RAIL CARS CONSIDERING VARIATIONS IN UTILIZATION*

Type and Length of Car	Solid Waste Shipment Density	Car Owning and Maintenance Cost Per Ton of Solid Waste Shipped at			
	(lbs./cu. ft.)	1 Trip/Year	100 Trips/Year	200 Trips/Year	300 Trips/Year
Box Cars - 70 Tons					
50.6 feet	20	$ 75	$0.75	$0.38	$0.25
	20**	($100)	($1.00)	($0.50)	($0.34)
Box Cars - 100 Tons					
50.6 feet	20	$ 80	$0.80	$0.40	$0.27
	20**	($106)	($1.06)	($0.53)	($0.36)
50.6 feet (All-Door)	60	34	0.34	0.17	0.12
Gondola Cars - 70 Tons (low side)					
65.6 feet	20	$173	$1.73	$0.87	$0.58
	60	58	0.58	0.29	0.19
Flat Cars - 70 Tons					
89 feet (2 containers at 40 feet)	20	$174	$1.74	$0.87	$0.58
Flat Cars - 100 Tons					
68 feet (3 containers at 20 feet)	20	$207	$2.07	$1.04	$0.69
	60	72	0.72	0.36	0.24
89 feet (2 containers at 40 feet)	20	$181	$1.81	$0.91	$0.61
	60	83	0.83	0.42	0.28

* Data slightly rounded.

** This comparison refers only to the space utilization of box cars in the shipment of unprocessed or shredded solid wastes. An adaptation of the box car to the loading and unloading of unprocessed solid wastes, i.e. top loading and side dumping, would increase the cost by about 30% of the values stated. The value adjustment is shown in the table in parenthesis.

2. Dedicated Freight Train Service

A second alternative is to use a dedicated train for the rail-haul of solid wastes. Such use eliminates the need to conform to regular freight schedules. Such service could accommodate even those communities which have infrequently scheduled regular freight service. It also allows flexibility with respect to the disposal site location.

3. Unit Trains

Unit trains typically travel between two points without stops enroute and generally pull from 70 to 100 or more cars. Some unit trains move over distances of 500 to 700 miles per day. A unit solid-waste train, however, could run economically with fewer cars and with stops along the route.

The cost per ton to the shipper via unit train averages less than half the rail industry average for regular freight service. The biggest difference is the elimination of switching in yards. With the bypassing of yards and the elimination of switching, the cost accounting problem for a unit train becomes less complex. The cost of train crews, fuel and oil, power, train servicing, loss and damage, and other items are direct and specific to the train. A single bill of lading for each train load reduces the paperwork and accounting.

Unit train pricing opens the door to a sound basis of rate making: "cost-based" rates. The attractive economics of unit trains to the railroads is marketed to shippers through a competitive price. Historical rate patterns related to conventional service are based on market competition or commodity values and have created a very complicated structure of rail tariffs.

Shipper furnished rail cars can bring about a still lower rate to the shipper. It is advantageous to both parties. Since a rail tariff is not a long term contract, the railroad is faced with the speculation of a possible diversion of their car equipment to other, more conventional services, in the event the shipper decided to change to some other transportation alternative. The rail tariff will reflect the higher expenses in that case. By furnishing the equipment himself the shipper pockets the full cost advantage of the unit train's low cost-potential for equipment utilization. Furthermore, carrier furnished equipment would have to be suitable for possible diversion to general use.

The empty return run of a unit train could become a payload of solid wastes. This alternative, unfortunately, is not universally applicable. There are few unit trains in operation; moreover, unit train operators cannot allow disruptive changes in their schedule or in train speed and there might be need for an extensive cleaning operation of the rail cars at the solid waste disposal site.

Nevertheless, the return haul approach should be carefully investigated. Two arguments can be cited in support of it. First, the cars in unit trains are ordinarily hoppers–either bottom or bottom side dumpers. They can accommodate solid wastes in the form of briquettes or–in the case of side dumpers–blocks up to one-third cubic yard. Second, most unit trains carry coal from mines–possible sites for refuse disposal – to urban centers – where major quantities of solid wastes originate.

4. Rent-A-Train

The Rent-A-Train concept was introduced by the Illinois Central (I.C.) Railroad. The I.C. plan as offered applies only to the shipment of specific agricultural commodities from originating points in the midwest to specific Gulf Coast ports. The present plan involves hauls of at least 600 miles one-way.

As constituted today, the plan offers a shipper eighty-six, 100-ton railroad owned cars in one cut plus motive power on short notice whenever requested. The cost consists of an annual charge of $1 million plus 1.5 mills per trailing ton-mile for a minimum 600-mile one-way haul. The annual charge of $1 million is reduced to $700,000 per train if the shipper or receiver furnishes the cars.

Interest in the concept arises from the significant reduction in freight cost when a user can arrange for an intensive utilization of the train. This is, of course, the case in the shipment of solid wastes by rail where large tonnages must be transported daily.

FACTORS GOVERNING THE TRAIN CONFIGURATION

Train configuration is primarily determined by the train load, the conditions of movement, and the utilization of the locomotive power available.

1. The Train Load

The total train load is made up of the total net load and the total deadweight of the cars. The net load of the train is given by the weight of the solid wastes it is to move. The deadweight varies with the type of freight car used. The deadweight per car varies specifically with differences in the load carrying capability. Here, size, i.e., economics of scale, come into play. On a very broad average, the deadweight of a 50-ton car amounts to 23-25 tons. In contrast the deadweight of a 70-ton car amounts to

28-30 tons while the deadweight of a 100-ton car ranges from 30-35 tons. The deadweight per train is directly proportional to the number of cars used of a given size and indirectly proportional to the increasing capacity of the cars used. This is indicated in Table 25 , Deadweight per Train, for net loads of 1,000, 2,000, 3,000, 5,000 and 8,000 tons of solid waste per train.

Table 25 indicates that almost one-third of the total train load is deadweight if 50-ton freight cars are used. The deadweight drops to about one-fourth if 100-ton cars are used. Thus, even if the solid waste shipment density allows full use of a freight car's load carrying capacity, the largest available cars should be used.

2. *Conditions of Movement*

In addition to the total train load, the conditions of movement influence the amount of locomotive power required per train. The conditions of movement are, as a rule, referenced in terms of the pull or push required to effect the movement. The force of the pull is expressed in pounds.

Tests have indicated that it takes from 16 to 20 pounds of pull per ton of train weight to start a train on a straight, level track in fair weather with moderate temperatures. Once the train is underway, the pull must overcome rolling resistance which, as a rule, is equated to about five pounds per ton of train.

The rolling resistance of the train is affected, of course, by grades, curvature of the track, and speed. As a rule, one percent of grade requires a pull of 20 pounds per ton of train. One degree of curvature requires an additional pull of 0.8 pounds per ton of train. An increase in the train speed from 10 to 50 miles per hour increases the pull requirements, on a broad average, by about 80 percent.

Thus, if a train would have to pass a one percent grade in a 15 degree curve at 10 miles per hour, the pull required would amount to 37 pounds per ton of train. It is assumed in this case that the train would neither go into the curve with a high speed nor stop in the curve. In case the train would have to stop in the curve on the grade, the necessary pull would amount to about 52 pounds per ton of train.

The foregoing information indicates why it is quite complicated to generalize on pull rates. Grades, curves, and speed possibilities or limitations vary between different movements as well as sections of individual movements. For example, the pull requirements vary substantially depending upon whether the grades and curves on a line do or do not coincide.

Pull requirements must be correlated to total train weight. Assuming a pull need of 45 pounds per ton of train, a 1,480 ton train – for example, a 50-ton car train with a 1,000 ton net load – would require about 66,600 pounds of pull for its movement. Under the same assumption, a 1,330 ton train – for example, a 100-ton car train with a 1,000-ton net load – would require about 59,850 pounds of pull. The total train load in these examples is derived from the data in Table 24 which assumes that a car carries its rated net load.

TABLE 25

DEADWEIGHT PER TRAIN AT VARYING NET LOADS AND DIFFERENT CAPACITY CARS (1)

Type of Car (2)	Deadweight in Tons per Train at Train Net Loads of				
	1,000 tons	2,000 tons	3,000 tons	5,000 tons	8,000 tons
50 Ton	480	960	1,440	2,400	3,840
70 Ton	400	800	1,200	2,000	3,200
100 Ton	330	660	990	1,650	2,540

(1) Figures slightly rounded

(2) Assumes full carload, i.e. 50 tons of solid waste on a 50-ton car, 70 tons on a 70-ton car, and 100 tons on a 100-ton car.

3. Locomotive Power

Locomotive power must be selected with respect to the total weight of the train to be pulled as well as the conditions of movement. On a very broad average straight purchase price of locomotive power is estimated to cost between $75 and $100 per horsepower unit. A range of selected locomotive price and performance data is given in Table 26, Selected Locomotive Power – Cost Data.

The data presented in Table 26 indicate that the purchase price for the tractive effort is from $3.20 to $5.08 per pound. The tractive effort includes the force needed to move the locomotive as well as the drawbar pull. The drawbar pull is the amount of force a locomotive can exert on its rear coupling to move the attached train of cars.

For diesel-electric locomotives, a distinction is frequently made between starting and continuous tractive effort. A diesel-electric locomotive cannot continue to exert maximum power for a prolonged period without damaging its traction or electric motors. Therefore, the continuous tractive effort for such locomotives is rated at about 50 to 70 percent of its starting tractive effort.

The drawbar pull of the locomotive is the equivalent of the tractive effort minus the pull required to move the locomotive itself. Tests have indicated that it also takes 16 to 20 pounds of pull per ton of weight to get the average locomotive moving. Thus, if the locomotive weighs 100 tons it is necessary to subtract 1,600 to 2,000 pounds from the tractive effort given to obtain the drawbar pull available.

TABLE 26
SELECTED LOCOMOTIVE POWER–COST DATA

Diesel-Freight "A" Units		**Average Weight/ Unit (tons)**	**Average Purchase Price (dollars)**	**Average Tractive effort/unit (lbs.)**	**Average purchase price/lb. Tractive effort**
Type B–B	2,000 hp	124-130	$206,000	44,823	$4.60
Type B–B	2,500 hp	130-135	208,000	51,385	4.01
Type B–B	3,000 hp	134	250,000	54,100	4.62
Type B–B	3,300 hp	135	260,000	54,100	4.81
Type B–B	3,600 hp	135	275,000	54,100	5.08
Type C–C	2,250 hp	180-195	246,000	72,240	3.41
Type C–C	3,600 hp	185-195	312,500	82,100	3.81
Diesel-Multipurpose "A" Units					
Type B–B	1,500 hp	125-129	180,000	41,700	4.32
Type B–B	2,000 hp	132-135	230,500	54,700	4.21
Type B–B	3,000 hp	130-135	243,000	54,700	4.44
Type B–B	3,000 hp	134	250,000	54,100	4.62
Type B–B	3,300 hp	135	260,000	54,100	4.81
Type B–B	3,600 hp	135	275,000	54,100	5.08
Type C–C	3,600 hp	185-195	312,500	82,100	3.81
Type C–C	2,000 hp	160-180	274,500	82,100	3.34
Type C–C	3,000 hp	195	290,000	90,600	3.20
Type C–C	3,300 hp	195	300,000	90,600	3.31
Type D–D	6,600 hp	268	500,000	109,400	4.57

Source: ElectroMotive Division, General Motors Company, and General Electric Company.

Thus, for a 1,000 ton net-load train requiring as previously indicated a 66,600 or a 59,850 pound pull, and assuming the continuous tractive effort at 70 percent of the starting or rated tractive effort, then it is necessary to select a locomotive with a drawbar pull of about 95,000 or 85,500 pounds respectively.

Selecting, for example, among the locomotives indicated in Table 26, one would take two Diesel-Freight "B-B" Units Type 2500 or one Diesel multipurpose type "C-C" 3,000 hp respectively under the assumption that about 18 pounds of pull are needed per ton of locomotive weight to move the locomotive. The difference in purchase price would amount to about $126,000.

This difference in purchase price is significant. The Internal Revenue Guidelines peg the life of the averagely used locomotive at 14 years. On a very broad average, locomotives are actively used about 50 percent of the time.

To allow for a higher service factor – probably the rule in dedicated service – it appears necessary to apply a 10-year depreciation period. As a result the straight annual depreciation cost would amount to $40,606 and $29,000 respectively. Using then a value of 75 percent of the annual cost for interest, finance charges and return on investment, the total fixed annual engine cost would amount to about $71,050 and $50,750 respectively.

At 100 trips per year the cost would amount to about $711 and $508 per trip and at 300 trips to about $237 and $169 per trip respectively. At a 1,000-ton net load per train the engine ownership cost in these examples would range from 17 cents to 71 cents per ton, a difference of about 400 percent caused wholly by variations in the selection and utilization of the rolling equipment;

Additional engine cost includes maintenance, labor, and fuel. Maintenance costs are frequently calculated at 20 cents to 30 cents per unit mile. Thus, maintenance could amount to 6 cents per ton for a 1,000 ton, 200 mile trip. Fuel is frequently calculated at four to six gallons per mile per unit. Thus, at five gallons per unit/mile and a cost of 15 cents per gallon the fuel cost would amount to $150 for a 200 mile round trip. This is the equivalent of 15 cents per ton at a net load of 1,000 tons per train. Additional fuel allowances are necessary for waiting time at a rate of seven to ten gallons per hour.

Thus, the mere engine owning and operating costs, excluding labor, range upwards from 38 cents to 92 cents per ton in these examples. In very broad calculations it is frequently assumed that wages amount to about $1.00 to $1.50 per train mile. This would add, for a 200 mile round trip, 20 cents to 30 cents to the engine cost per ton of train net load.

In the overall, the foregoing data suggest that the engine cost represents a major cost factor in the make-up of rail rates. At 1,000 tons net load per train, the data indicate that the cost increment for a 200-mile round trip may range from 48 cents to $1.12 per ton.

The data represent broad approximations and comprise only cost factors which are of general concern. Weather factors also may have to be considered. For example wet tracks and temperatures below freezing reduce the handling power of locomotives.

TRACK COST

A share of the track cost, i.e., maintenance of way and operations including items such as signals and gates, must be charged to the operating costs. A specific allocation of track cost requires an analysis of the expenditures which are allocated to the specific portion of the track used. Furthermore, track utilization factors must be considered, e.g., the tonnage that rolls over the track within a given period of time.

On a broad average, expenditures for track maintenance and operations equal about 2 to 4 cents per net ton mile. Thus if 1,000 tons are shipped over a distance of 100 miles (100,000 ton miles) the track cost would amount to about $300 or 30 cents per ton.

The cost of track operation and maintenance varies widely. Selection of an infrequently used line, for example, may require a significant amount of catch-up maintenance for the service required, i.e., load and speed. However, it must also be recognized that alternative routes are frequently available. A trade-off analysis will determine the most advantageous route in terms of the total system.

To gain access to desirable sites for transfer stations and disposal, it may be necessary in certain instances to build new tracks. These tracks should be capable of carrying heavy loads and accommodate heavy traffic. There are several elements of cost involved in laying track. These include labor, equipment, land acquisition and right-of-way expenditures, engineering, grading of both terrain and bed, the laying of ballast, the actual positioning and joining of ties and rail, and the cost of rails, ties, anchors, and other materials. The actual costs will necessarily depend to a large degree on the specific conditions in a given lcoation. However, a general estimate reported by railroad personnel is given at about $20 to $25 per foot, excluding land.

GENERAL CONDITIONS

Broadly speaking, rail-haul costing requires consideration of expenses for: a. the operations of way structures and equipment, b. the operations of yards, (and of way-freight and through-freight trains) c. general overhead and operating expenditures and d. the investment. Each of these groups contains many items which may or may not apply to the costing out of a given rail transport service.

For example, the Interstate Commerce Commission lists about 55 separate cost items to be reported for the operating expenses incurred by a railroad in just the maintenance of way and structures. An inspection of these cost lists suggests that some expenditures might not apply to the rail haul of solid wastes and that other expenditures, such as yard maintenance, will only apply if yards are needed for a given solid-wastes rail-haul system. All the rail investment and operating cost elements will, of course, have to be analyzed, evaluated, and packaged in terms of a specific movement in order to arrive at the actual cost.

The ICC differentiates between way-freight trains and through-freight trains. Way-freight train costs differ from through-freight train costs because way trains are operated as a "local" train with the right to do switching work. Thus, they distribute empty cars to the shipper and pick up the loaded ones. Only a small part of the way-train costs are incurred in the line-haul movement of shipments. In contrast, through-freight trains spend the greater part of their time in moving traffic over the line between crew-changing points. Very little of their cost is attributable to switching.

In addition to the through-trains and way-trains there are specific switching units, crew and engine, which operate in and around major railroad terminals. They service the industries close to terminals by delivering loads, pulling loads, and placing empties.

Switching can be quite expensive, up to $90 per car, if multi-line switching is involved. As a rule the charge amounts to $7.50 per switch or $15 to get one car on and off a train plus another $15 to repeat the same operation on the other end of the line. For 50 tons of net load per car, the switching cost thus might range from 60 cents to $1.80 per ton; and for 100 tons per car, from 30 cents to 90 cents per ton.

However, there are many variations depending upon the terminal operations and the location of customers. Some way-trains will cover a section of only 20 to 30 miles and will switch on the way. Others will travel 100 miles or more in a day and haul some through-cars in the direction of their movement. Furthermore, through-trains may be operated like way-trains and do some local setting out or picking up of freight cars. In order to make their schedules, such trains may have less tonnage than that assigned to through-trains which do no local work.

Thus, depending upon local factors (e.g., the number of transfer stations or communities to be served enroute and the haul distance) the cost patterns of either way- or through-freight trains might apply. The through-train cost might, as a rule, amount to only 70 to 80 percent of the way-train cost per unit of movement. In almost all instances, the cost per carload or per-ton-mile is higher for way-trains than through-trains.

The cost differential between way- and through-trains suggests that the operations for the rail-haul of solid wastes be developed as much as possible to utilize through-train operating conditions. Local switching is expensive and should be minimized by both the location and throughput of transfer stations as well as the configuration of the entire rail-haul operation. From an operating cost point of view, rail-haul of solid wastes should use unit-train or dedicated service rather than regular freight train shipment patterns.

Terminal facility costs also must be identified in the total cost of operation. These costs appear to be strongly influenced by the operation of transfer stations and their location in a rail network. It is likely that there will be some terminal costs at the origin and perhaps the destination of some rail-haul systems.

In an example published by the ICC for a low-volume waste paper and scrap metal movement, terminal costs amounted to 52 percent of the total costs. For our purposes this could be considered a maximum cost. Terminal costs are incurred, however, only where regular scheduled, non-dedicated service is used. For the cost models used in this study, no terminal changes were estimated to be applicable.

The data presented thus far on the rail-haul cost suggest that many models can be built depending upon differences in the many variables involved. Thus the following discussions are confined to the presentation of "order-of-magnitude" values in three selected costing approaches.

1. Unit Train Costing Patterns

Tables 27, 28, and 29 present costs representing average roundtrip freight rate charges for unit trains used for hauling solid wastes. The three tables differ in car implementation. Table 27 gives unit-train freight-rate characteristics based on shipper-owned or furnished cars. The data in Tables 28 and 29 are

TABLE 27

REFUSE UNIT-TRAIN FREIGHT RATE CHARACTERISTICS IN DOLLARS PER TON SHIPPER OWNED CARS

Number of Cars per Train	One-way Trip (Miles)								
	50			100			150		
	Load in Tons/Car of the Same Carrying Capacity								
	50	75	100	50	75	100	50	75	100
5	6.56	4.39	3.32	8.88	5.98	5.52	11.21	7.56	5.73
10	3.68	2.47	1.88	4.93	3.35	2.55	6.19	4.22	3.21
25	2.16	1.45	1.14	2.81	1.91	1.48	3.47	2.39	1.84
50	1.58	1.08	.82	2.02	1.39	1.09	2.46	1.72	1.36
75	1.38	.95	.73	1.76	1.22	.96	2.12	1.50	1.18
100	1.30	.88	.68	1.61	1.14	.88	1.95	1.38	1.10
120	1.21	.82	.64	1.52	1.07	.85	1.83	1.30	1.03

	200			250			300		
	50	75	100	50	75	100	50	75	100
5	13.54	9.14	6.93	15,88	10.71	8.14	18.20	12.30	9.35
10	7.47	5.08	3.90	8.71	5.95	4.56	9.97	6.81	5.24
25	4.12	2.85	2.23	4.78	3.32	2.59	5.43	3.78	2.96
50	2.90	2.04	1.61	3.35	2.35	1.88	3.78	2.68	2.13
75	2.48	1.77	1.41	2.86	2.04	1.62	3.22	2.31	1.87
100	2.28	1.62	1.31	2.62	1.89	1.52	2.96	2.13	1.72
120	2.13	1.53	1.26	2.45	1.76	1.43	2.75	1.99	1.61

Note: Return trip is assumed empty.
No mileage allowance paid by carrier.
Costs reflect ICC authorized rate increases to Jan., 1971. However, as previously mentioned, these rates may not be actually charged for solid-waste rail-haul, since ICC does not regulate waste rates.

based on railroad ownership of cars; the purchase price per car being $15,000 and $25,000 respectively.

The tables are general and do not account for all situations. For example, while some hauls require one crew other hauls of identical length require two or three crews because of differing regulations. This could result in a rate difference of 25 to 50 percent. Furthermore, the figures in the tables reflect many assumptions about the nature of the service; changing the assumptions will change the cost.

The major assumptions in these examples are:

1. Cars are in assigned-service, loaded to their *full carrying* capacity, and moved on a scheduled basis. Allowance is made for a 20 percent variation in the load per train on a weekly basis.
2. Multiple car lots remain together. Thus, if the 25-car option is selected, it would not be permissible to use only ten of the cars.
3. Cars are spotted in one cut at one location. Cars will not be moved around by the railroad at the transfer station or landfill site.
4. Only 12 hours (excluding weekends) is allowed for loading and unloading, e.g., eight at the transfer and four at the disposal site.
5. Loading and unloading, cleaning of cars, etc.

TABLE 28
REFUSE UNIT-TRAIN FREIGHT RATE CHARACTERISTICS IN DOLLARS PER TON, CARRIER OWNED CARS, CAR COST $15,000

Number of Cars per Train	One-way Trip (Miles)								
	50			100			150		
	Load in Tons/Car of the Same Carrying Capacity								
	50	75	100	50	75	100	50	75	100
5	7.59	5.08	3.84	9.91	6.67	5.03	12.24	8.24	6.24
10	4.71	3.16	2.40	5.96	4.04	3.07	7.22	4.90	3.73
25	3.19	2.15	1.64	3.84	2.61	1.99	4.50	3.08	2.36
50	2.61	1.77	1.33	3.05	2.15	1.50	3.49	2.41	1.87
75	2.41	1.64	1.25	2.78	1.91	1.47	3.15	2.18	1.70
100	2.31	1.56	1.19	2.64	1.83	1.41	2.98	2.07	1.61
120	2.24	1.49	1.16	2.55	1.76	1.36	2.85	1.99	1.55

	200			250			300		
	50	75	100	50	75	100	50	75	100
5	15.09	10.17	7.71	17.42	11.42	8.91	19.74	13.33	10.12
10	9.01	6.11	4.67	10.27	7.02	5.33	11.51	7.84	6.00
25	5.15	3.54	2.74	5.81	4.01	3.10	6.46	4.47	3.48
50	4.44	3.07	2.39	4.88	3.38	2.64	5.33	3.71	2.90
75	4.04	2.80	2.18	4.40	3.07	2.40	4.78	3.35	2.64
100	3,83	2.65	2.08	4.17	2.92	2.29	4.51	3.16	2.50
120	3.67	2.56	2.00	4.00	2.79	2.21	4.30	3.02	2.39

Note: Return trip assumed empty.
Costs reflect ICC authorized rate increases to Jan., 1971.

is not performed by the railroad.

6. Cars are empty on the return trip, and
7. Each haul pattern is supplied with 2.2 times the necessary cars to provide for more relaxed service requirements. It might be remembered in this context that the turn-around time is more a function of the trip than of the distance.

These figures cannot and should not be used to determine the cost of any specific movement, let alone the rate that might be quoted.

The purpose of tables 27-29 is to show the magnitude of the many trade-offs that are available. For example, figures in Table 27 indicate that it costs $3.32 per ton to ship 500 tons in five 100-ton shipper-furnished cars over a distance of 50 miles, but it costs $6.56 per ton, or $3.24 more, to ship the same amount over the same distance in ten 50-ton cars. Furthermore, it costs $5.52 per ton to ship 500 tons in five 100-ton cars over a distance of 100 miles. In contrast, it costs $2.97 less, or $2.55 per ton, if 1,000 tons are shipped in ten 100-ton cars over the same distance.

The data indicate that unit-train operations are more expensive than regular train costs if only a small amount of materials is shipped. For example, taking Table 28, it costs $9.91 per ton to ship 250 tons of material in five 50-ton railroad-owned cars over a distance of 100 miles. These costs are incurred primarily because of under-utilization of locomotive power – in this case, an engine pulling only five cars while it is capable of much more.

In applying unit-train costs to a solid-waste rail-haul system, it is first necessary to balance the economics of scale with the amount of solid wastes that might be generated in a given area. The data show that it would cost $2.55 per ton to ship 1,000 tons in ten 100-ton shipper-furnished cars over a distance of 100 miles and $1.48 per ton if 2,500 tons were shipped under the same circumstances. If the railroad owns the cars and if each car costs $15,000, then these costs would be $3.07 and $1.99 per ton

TABLE 29

REFUSE UNIT-TRAIN FREIGHT RATE CHARACTERISTICS IN DOLLARS PER TON, CARRIER OWNED CARS, CAR COST $25,000

	One-Way Trip (Miles)								
		50			100			150	
Number of Cars per Train	Load in Tons/Car of the Same Carrying Capacity								
	50	75	100	50	75	100	50	75	100
5	8.27	5.54	4.18	10.59	7.11	5.38	12.93	8.70	6.59
10	5.39	3.62	2.74	6.65	4.48	3.41	7.90	5.36	4.07
25	3.85	2.61	1.98	4.52	3.07	2.34	5.19	3.54	2.70
50	3.30	2.22	1.68	3.73	2.53	1.95	4.17	2.87	2.22
75	3.10	2.10	1.59	3.47	2.36	1.82	3.83	2.64	2.04
100	3.01	2.02	1.54	3.33	2.28	1.75	3.67	2.53	1.95
120	2.92	1.96	1.50	3.24	2.22	1.70	3.54	2.45	1.89
		200			250			300	
	50	75	100	50	75	100	50	75	100
5	16.11	10.86	8.22	18.45	12.44	9.43	20.77	14.01	10.64
10	10.04	6.80	5.19	11.30	7.66	5.85	12.54	8.53	6.52
25	5.84	3.99	3.08	6.50	4.46	3.45	7.15	4.92	3.82
50	5.48	3.76	2.90	5.91	4.07	3.16	6.36	4.40	3.42
75	5.07	3.48	2.69	5.43	3.76	2.92	5.81	4.04	3.15
100	4.86	3.35	2.59	5.20	3.60	2.80	5.54	3.84	3.02
120	4.84	3.25	2.52	5.03	3.48	2.71	5.33	3.71	2.91

Note: Return trip assumed empty
Costs reflect ICC authorized rate increases to Jan., 1971.

respectively.

Although the given data represent only one example of solid-waste rail-haul cost characteristics, they are sufficient to draw some general conclusions. Analysis of the shipment tonnage, for example suggests that a solid-waste rail-haul system requires anchor communities to establish an economical base for operations. Such anchor communities are defined by the amount of solid waste generated in the area and the cost of competitive disposal methods. In view of the data in this report, it appears reasonable to define an anchor community as one having 1,000 or more tons of solid waste to dispose of daily.

The data also suggest that shipments be made in 100-ton or larger cars wherever possible. At 1,000 tons per train the cost per ton could range from $2.00 to $2.50 for a one-way shipping distance of less than 100 miles. The cost appears to be the same for both shipper- and railroad-furnished cars, since the cost of car leasing or ownership incurred by the shipper would have to be added to the total transport cost.

These costs include the individual items of expense previously discussed including rail car, engine, fuel, labor, terminal, switching, etc.

Overall, the economics of scale in unit-train operations may enable solid-waste rail-haul to be a competitive solid waste disposal alternative.

2. *The Effect of Material Density*

Differences in the density of the shipped materials affect the cost of unit-train operations. However, the density effects can be improved by the choice of railroad cars.

TABLE 30

ECONOMIC CHARACTERISTICS IN DOLLARS PER TON AS AFFECTED BY VARIATIONS IN DENSITY (BASED ON A 100-MILE HAUL IN UNIT TRAIN OPERATIONS)

Total Payload of Train (tons)	Hi-Cube Car Density Lb/Cu. ft. 10	Hi-Cube Car Density Lb/Cu. ft. 25	Gondola Car Density Lb/Cu. ft. 30	Gondola Car Density Lb/Cu. ft. 70-80
600	$5.60	$3.65	$4.00	$2.20
1,200	4.25	2.55	3.35	1.65
1,800	3.75	2.10	3.15	1.45

Table 30, Economic Characteristics as Affected by Variations in Density, contains cost characteristics of shipping materials of different densities in different types of cars. The information supports the contention that solid wastes should be compacted for a maximum performance system.

Table 30 compares Hi-Cube covered hopper cars useable capacity, 7,000 cu. ft. for the shipment of loose solid waste with gondola cars for the shipment of baled waste. Two density values are given in each case to indicate the effects of various processing results.

The assumed weight of 25 lb/cu. ft. represents, for this example, a maximum transport density for totally unprocessed solid wastes which have received some degree of compaction. The actual density of unprocessed solid wastes is significantly lower and this value approximates the maximum density of uncompacted, shredded; solid waste materials. The choice of 75 lb/cu. ft. represents a weight just under the maximum density of 80 lb/cu. ft. which represents the calculated maximum average density that can be obtained with "normal," dry solid waste mixtures by scrap baler compaction in the absence of springback, i.e., with strapping, or some other form of bale confinement.

The data in Table 30 indicate that the cost differential for the shipment of unprocessed, as well as highly compacted, solid waste decreases with an increase in the total payload of the train. At a payload of 1,800 tons per train and a maximum density of 25 lb/cu. ft. for the unprocessed materials, the cost difference with respect to 70-80 lb/cu. ft. materials might be as little as 65 cents per ton. At a 600-ton payload per train and material density of 10 lb/cu. ft. for the unprocessed wastes, the cost difference may amount to as much as $3.40 per ton.

Overall, the data in Table 30 show a cost decrease when density of materials being shipped and net load per train increase.

3. Cost Characteristics for 1,000-tons Per Day Rail-Haul Movements

The data used in this report for the analyses of railroad cars, engines, tracks, etc. can be used to establish a third data input for rail-haul cost estimates.

To keep the calculations simple, it was decided to vary only the engine ownership cost which represents the major cost variable. The car costs were taken from the quotation for leased cars, to represent a situation with a minimum initial cash outlay. All other costs are based primarily on ton-mile breakdowns and thus do not change with variations in the equipment utilization.

Numerous variations of basic cost patterns are not only possible but likely. As the following cost estimates, based on two different rates of equipment utilization show, these costs may range between $1.51 and $3.20 per ton. Nevertheless, the data in their totality suggest as reasonable the conclusion that in 1000-ton per day rail-haul systems the cost for the rail-haul link may be estimated roughly at $2.00 to $2.50 per ton, excluding terminal costs.

Cost Patterns, Varying Number of Trips and Processing of Wastes

	Processed		Unprocessed	
	100 (trips per year)	300 (trips per year)	100 (trips per year)	300 (trips per year)
Engine Ownership	0.17	0.24	0.51	0.71
Fuel	0.15	0.15	0.15	0.15
Engine Maintenance	0.06	0.06	0.06	0.06
Crew Wages	0.25	0.25	0.25	0.25
	0.63	0.70	0.97	1.17
Tract Cost	0.30	0.30	0.30	0.30
Car Cost	0.12	0.25	0.34	0.75
	1.05	1.25	1.61	2.22
25% Overhead	0.26	0.31	0.40	0.56
	1.31	1.56	2.01	2.78
15% Contingencies	0.20	0.23	0.30	0.42
Cost per ton	1.51	1.79	2.31	3.20

In evaluating the data on the rail haul link it must be stressed that the presently existing conditions of the railroads are fully taken into account. However, it must also be recognized that operating rules, including work rules, are subject to change and that wide differences can exist among various local situations. The data presented are based on ICC-territory-wide averages. This implies that in certain areas, depending upon local conditions, the cost for the actual rail haul of the wastes may be higher or lower than those indicated.

In addition, governments, railroad union, and management appear to be pioneering new operating designs which may cut costs or arrest price increases. The new approaches are intended to actually strengthen performance considering human factors as well as increased competition for new and old business.

EFFECT OF RAIL NETWORK

The solid-waste rail-haul network is basically defined by the existing rail network. Disregarding local ordinances or state laws, the system appears capable of functioning equally well intrastate or interstate. Thus, an initial intrastate system might be expanded to interstate as the operation of the disposal facility is proven acceptable to the public and local authorities.

A rail network analysis represents a complex undertaking. Some tentative results of such analyses are shown on maps in Figures 18 to 21. The maps cover the states of Ohio, Michigan, Indiana, and Pennsylvania.

The maps in the four figures present the available information in a highly simplified way to illustrate the basic approach and its effects. The following constraints should be kept in mind in reviewing the maps:

1. not all communities are indicated which might benefit from the rail-haul of solid wastes;
2. the network confines itself to selected tracks of the Penn Central Railroad to avoid inter-railroad switching charges and an increase in cost which could result from an interline movement as such;
3. the lines indicate how far solid wastes can be shipped at a cost of no more than $2.50 per ton at the relatively large volume levels attainable from the communities indicated;
4. other routes based upon Penn Central tracks or trackage rights could be chosen; and
5. the potential for combining regional solid waste/truck trailer operations with a solid-waste rail-haul system is not indicated.

A maximum rate of $2.50 per ton was chosen as a result of the previous analyses. Thus, the network analysis answers the question of how far solid wastes can be shipped from major metropolitan centers if one is not willing to pay more than $2.50 per ton for transportation. Differences in the lengths of the lines therefore represent differences in the solid waste tonnages generated by the communities served, and potentially available for rail-haul.

The portions of line overlap indicate where potential disposal sites might be located if one site is to serve a number of metropolitan centers. Thus the network analysis shows that rail-haul of solid wastes increases the flexibility for the location of disposal sites; where even greater economics of scale for disposal might be achieved.

For example, Figure 18, the State of Ohio map, suggests that the solid waste from the City of Columbus might be shipped for $2.50 per ton or less all the way to Toledo, Cincinnati, or Middleport, and almost to Cleveland. Cincinnati's wastes might be shipped for the same cost to half way between Columbus and Cleveland, almost half way between Columbus and Toledo, and about three-quarters of the way between Columbus and Middletown. Where the lines overlap, investigations should be conducted to locate disposal sites.

As a result of flexibility in the location of disposal sites, many areas might compete for solid-waste rail-haul disposal operations due to the economic benefits that could result. To some degree, the disposal operations may produce benefits comparable to those derived from locating a new industrial plant in a community, particularly should reclamation of solid waste materials become feasible.

An example of the number of site options made available through rail-haul is given in Figure 22, Survey of Potential Landfill Sites. This example covers only the southeastern part of Michigan and not the total state. Nevertheless, one aerial photo-survey led to identification of 20 potential sites which met the following requirements:

a. existence of a rail spur or proximity to rail line with reasonable terrain features to construct a spur;
b. large size or capability of considerable expansion;
c. low density of population in the immediate vicinity;
d. screening by natural vegetation and landform features;
e. on-site availability of cover material;
f. absence of flood plains, natural drainage in favor of the site in terms of sanitary landfill requirements, apparent absence of groundwater problems;
g. favorable local road pattern, general transportation network, and land use.

The 20 sites are indicated by numbers which were assigned arbitrarily and do not reflect any ranking. Photographs of typical locations are contained in Appendix C.

Overall, the network analyses indicate that it may

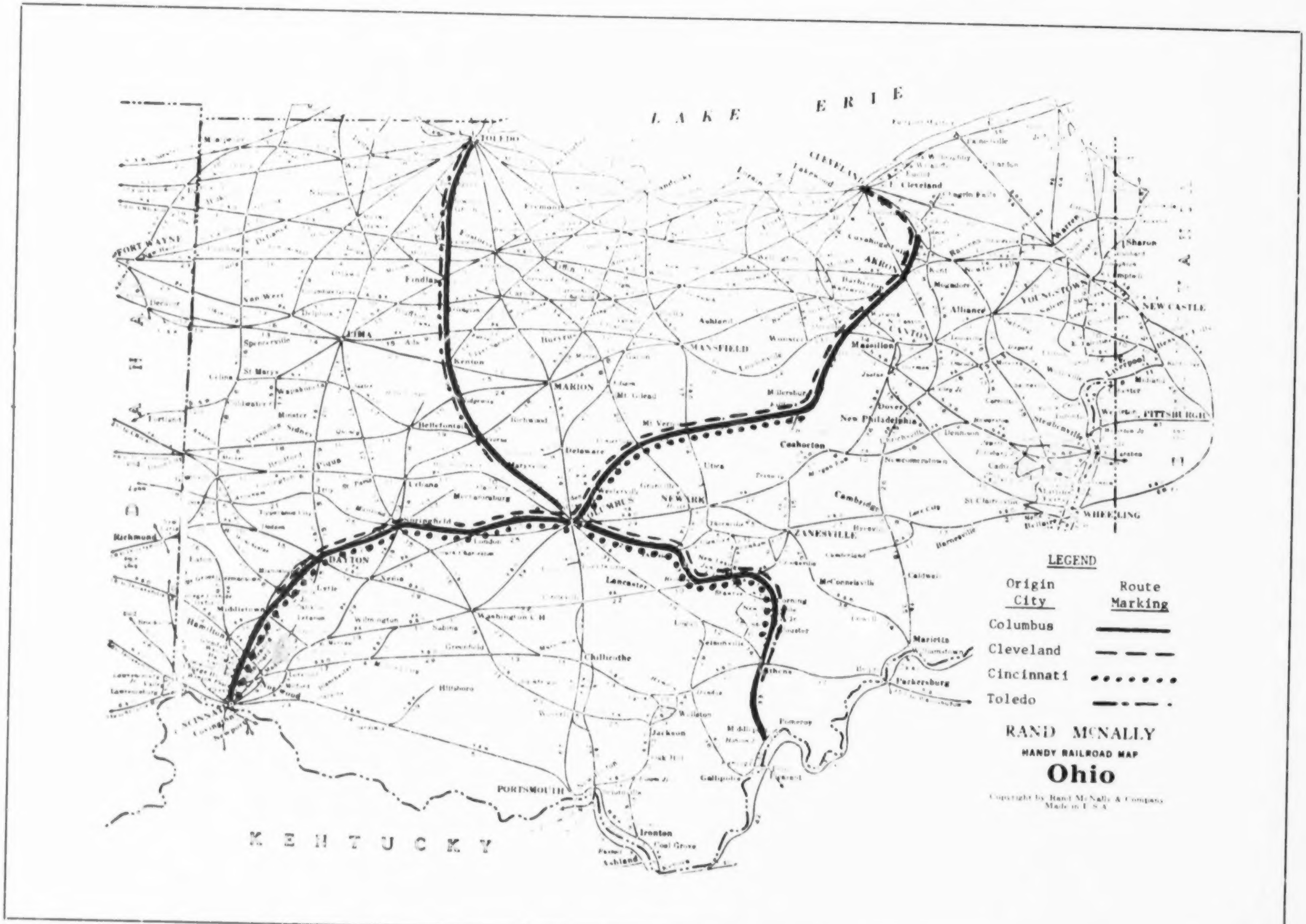

LAKE ERIE
KENTUCKY
TOLEDO
CLEVELAND
AKRON
CANTON
YOUNGSTOWN
COLUMBUS
DAYTON
Springfield
CINCINNATI
ZANESVILLE
NEWARK
MARION
MANSFIELD
LIMA
FORT WAYNE
PITTSBURGH
WHEELING
PORTSMOUTH
Athens
LEGEND
Origin City
Route Marking
Columbus
Cleveland
Cincinnati
Toledo
RAND McNALLY
HANDY RAILROAD MAP
Ohio
Copyright by Rand McNally & Company
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FIGURE 18

TENTATIVE SOLID WASTE RAIL-HAUL NETWORK, OHIO

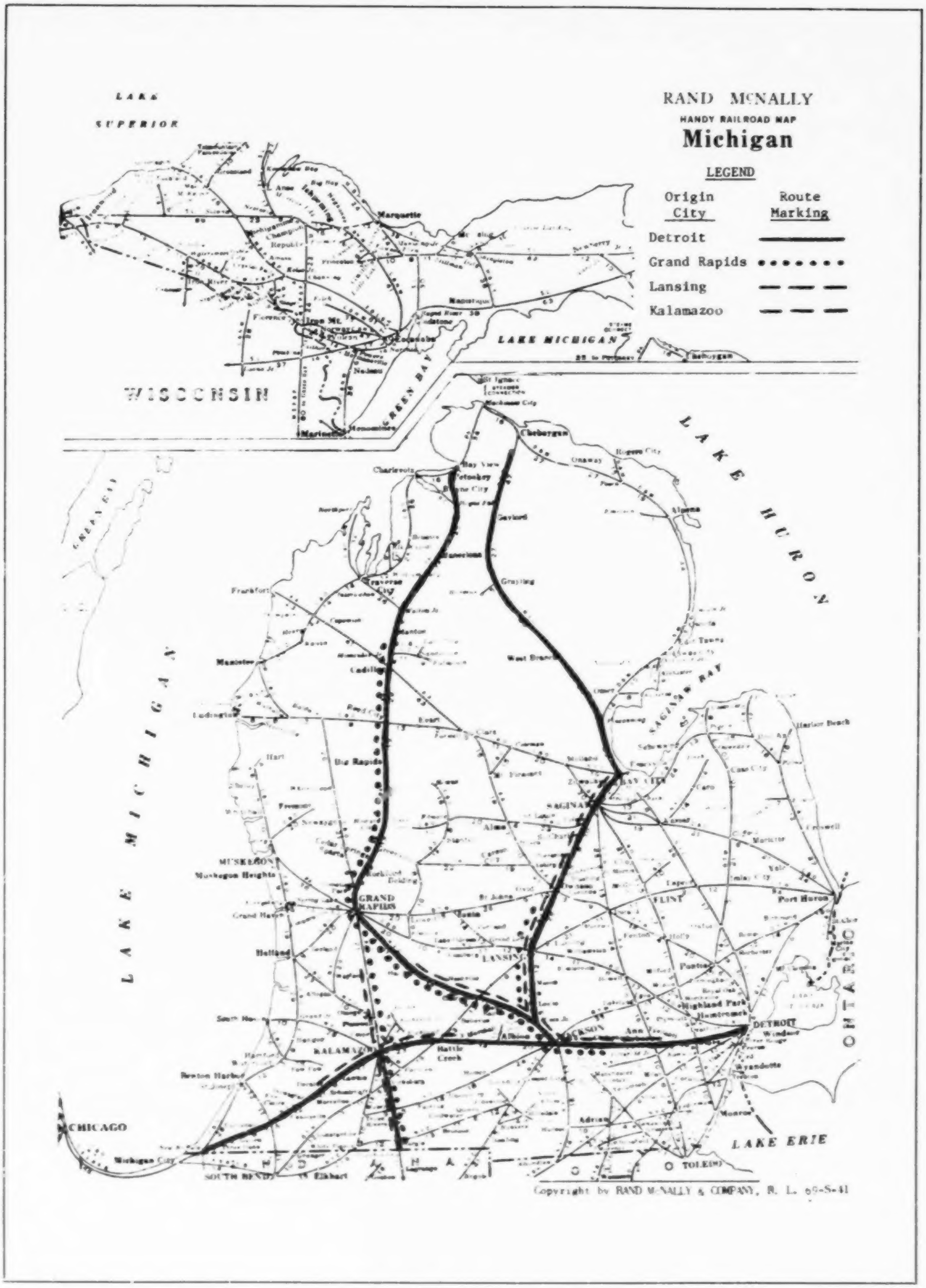
RAND McNALLY
HANDY RAILROAD MAP
Michigan
LEGEND
Origin City
Route Marking
Detroit
Grand Rapids
Lansing
Kalamazoo
LAKE SUPERIOR
Marquette
Iron Mt.
Escanaba
Menominee
Marinette
LAKE MICHIGAN
GREEN BAY
WISCONSIN
Cheboygan
Petoskey
Charlevoix
Gaylord
Grayling
Traverse City
Frankfort
Manistee
Cadillac
Ludington
West Branch
Big Rapids
Muskegon
Muskegon Heights
Grand Haven
Holland
GRAND RAPIDS
LANSING
SAGINAW
BAY CITY
FLINT
Port Huron
Pontiac
DETROIT
Windsor
Wyandotte
Monroe
JACKSON
Ann Arbor
Battle Creek
KALAMAZOO
Benton Harbor
St. Joseph
Adrian
TOLEDO
CHICAGO
Michigan City
SOUTH BEND
Elkhart
LAKE HURON
SAGINAW BAY
LAKE ERIE
ONTARIO
INDIANA
OHIO

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FIGURE 19

TENTATIVE SOLID WASTE RAIL-HAUL NETWORK, MICHIGAN

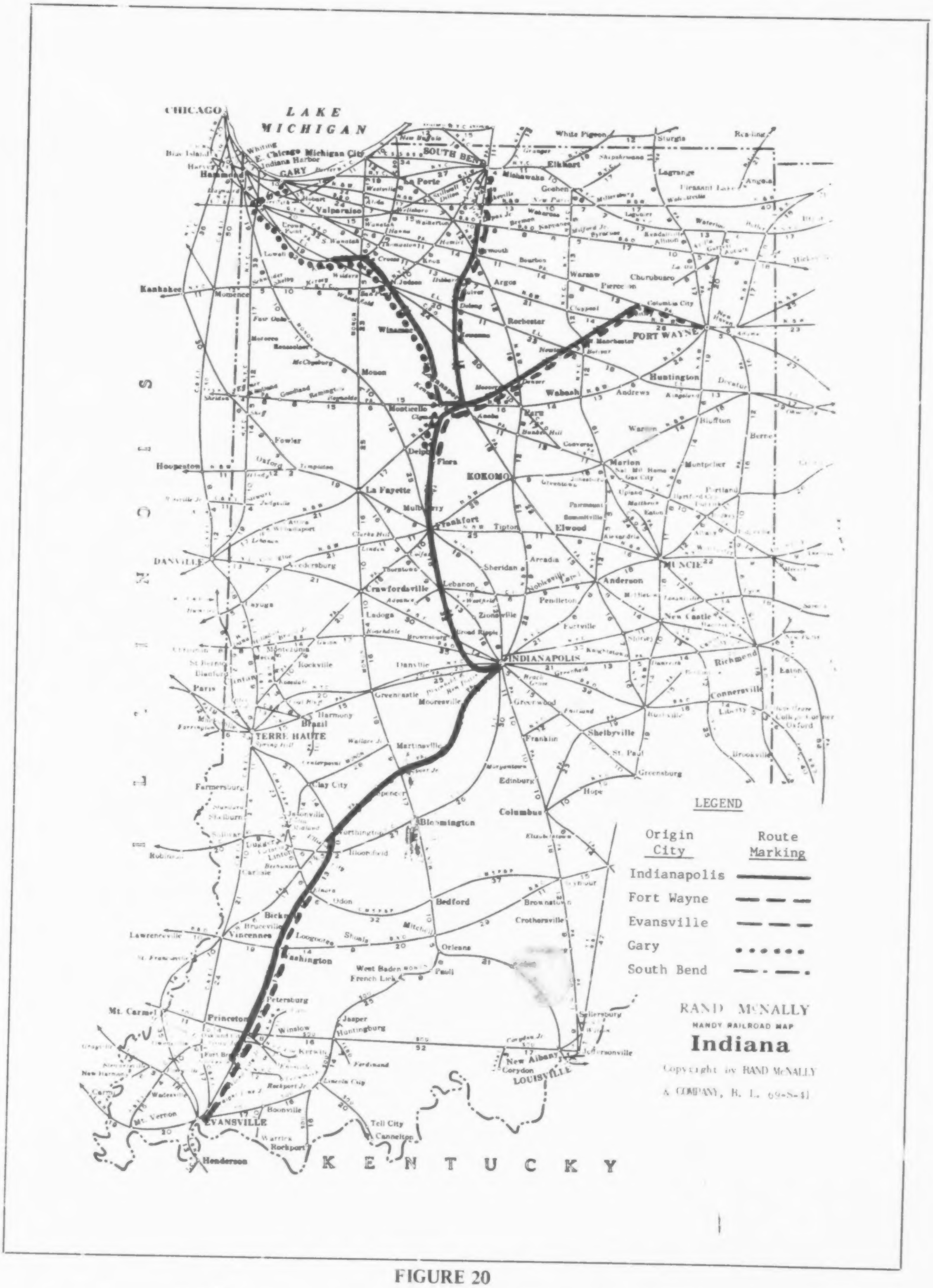
CHICAGO
LAKE MICHIGAN
GARY
SOUTH BEND
FORT WAYNE
KOKOMO
INDIANAPOLIS
TERRE HAUTE
EVANSVILLE
KENTUCKY
LEGEND
Origin City
Route Marking
Indianapolis
Fort Wayne
Evansville
Gary
South Bend
RAND McNALLY
HANDY RAILROAD MAP
Indiana
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FIGURE 20
TENTATIVE SOLID WASTE RAIL-HAUL NETWORK, INDIANA

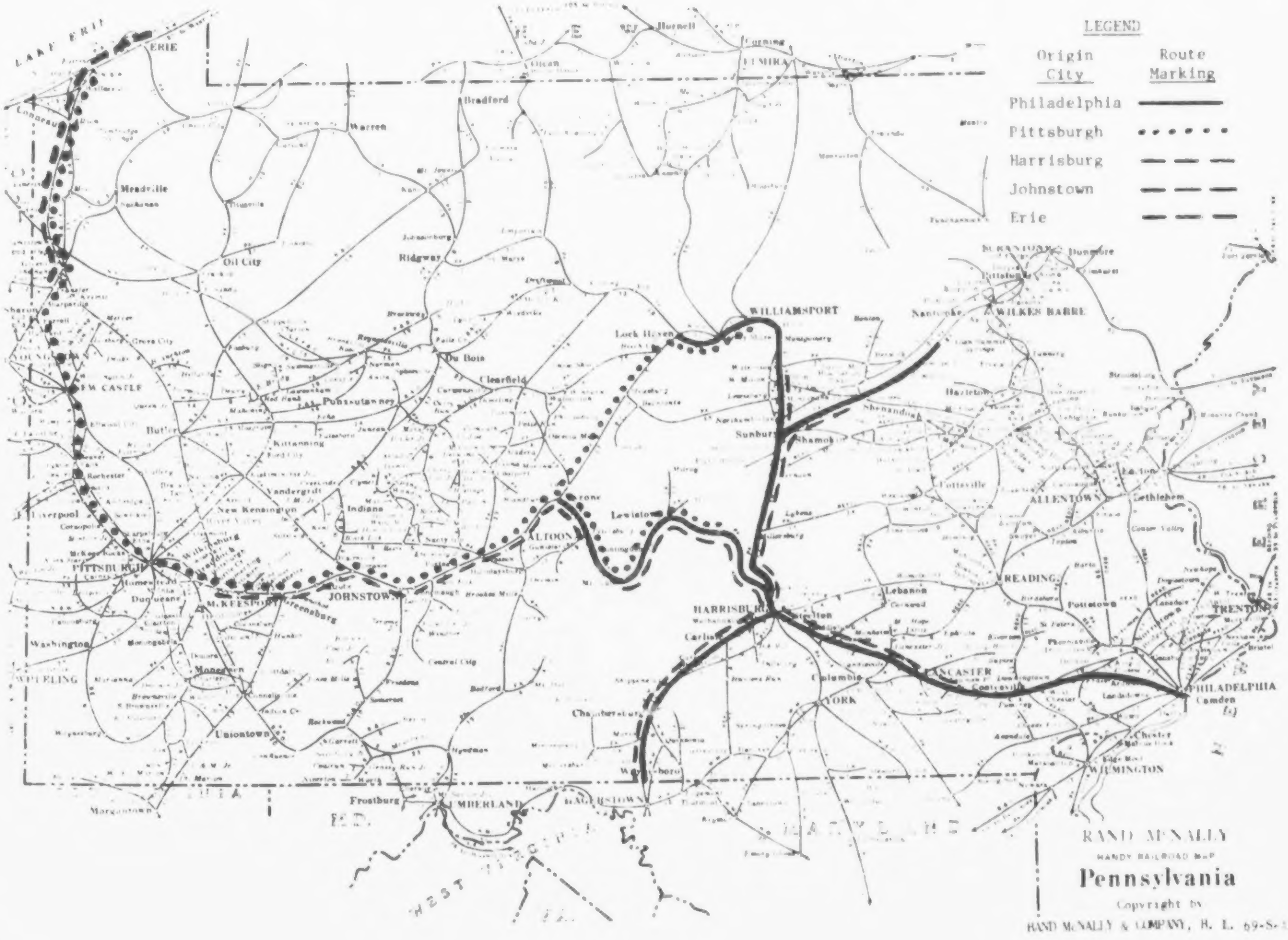
LEGEND
Origin City
Route Marking
Philadelphia
Pittsburgh
Harrisburg
Johnstown
Erie
RAND McNALLY
HANDY RAILROAD MAP
Pennsylvania
Copyright by
RAND McNALLY & COMPANY, R. L. 69-S-11
LAKE ERIE
ERIE
Meadville
Oil City
Warren
Bradford
Ridgway
Du Bois
Clearfield
Lock Haven
WILLIAMSPORT
Sunbury
Shamokin
Shenandoah
Hazleton
Nanticoke
WILKES BARRE
Pottsville
ALLENTOWN
Bethlehem
Easton
READING
Pottstown
TRENTON
PHILADELPHIA
Camden
Chester
WILMINGTON
LANCASTER
Columbia
YORK
Lebanon
HARRISBURG
Carlisle
Chambersburg
Waynesboro
HAGERSTOWN
CUMBERLAND
Frostburg
Lewistown
Tyrone
ALTOONA
JOHNSTOWN
Greensburg
McKEESPORT
PITTSBURGH
Homestead
Duquesne
Washington
WHEELING
Uniontown
Morgantown
Indiana
Punxsutawney
Kittanning
Butler
NEW CASTLE
New Kensington
Vandergrift
Beaver
Rochester
Hornell
Olean
ELMIRA
Corning
MARYLAND
WEST VIRGINIA

FIGURE 21

TENTATIVE SOLID WASTE RAIL-HAUL NETWORK, PENNSYLVANIA be possible to serve from 70 to 80 percent of the population in various states with the existing rail network. This might be accomplished by the establishment of only two or three disposal sites per state.

COMPETITIVE MODES OF TRANSPORT

To evaluate the potential of a rail-haul system the most economical method of transport must be determined. The principal contenders for bulk transport of large volumes of material are rail, highway trucks, (tractor-trailer combinations), and barges. Long distance pipelines could develop into a fourth system at some time in the future. However, at present, the transport of solid wastes by long distance pipeline is beset with too many problems in total system economics and pollution potential.

To establish a valid comparison requires that the underlying models be comparable. Consequently, the following analyses are based upon the following constraints:

a. a volume of 1,000 tons per shipment at a density of 20 lb/cu. ft. for unprocessed and shredded solid wastes and of 60 lb/cu. ft. for high-pressure/baled solid wastes;
b. a dedication of the equipment to the solid-waste service;
c. a distance of 100 miles one-way or 200 miles round trip;
d. a one 8-hour shift operation at the transfer station;
e. daily removal of the wastes from the transfer station excluding Sundays and holidays, and
f. a variation in the number of trips ranging from 100 to 300 trips per year.

Many model variations are possible. However, the above constraints reflect a minimum basic rail-haul system; it is in this context that the initial decisions on whether to employ rail-haul would be made.

A big handicap to economical hauling by truck is the relatively small maximum net load about 20 tons that a single tractor-trailer rig is permitted to haul in one trip.

The basic operating conditions of highway tractor-trailer units imply that a tractor pulls, as a rule, only one trailer at a time whether loaded or empty. The overall travel speed is about 50 miles per hour which leads to a *line-haul* time of 4 hours for a 200 mile round trip. Each unit is assumed to be manned by one operator, the driver. Due to regulations, he may spend not more than 10 hours per day on the job.

For this example, at the speed and distance given, a driver cannot make more than two trips per period of operation. To allow for sufficient time for the loading and unloading of the trailers, it was assumed that the trailer would make one trip per operating period while the tractor and the driver would make two trips. Because of net-load limitations, there are no significant cost differences between densities of 20 lb/cu. ft and 60 lb/cu. ft.

A 1,000-ton per 8-hour shift system would require 50 trailers, 25 tractors, and 25 drivers. A trailer is estimated to cost about $8,000 and a tractor $15,000. Thus the total straight purchase price of the transportation equipment would amount to $400,000 for the trailers and $375,000 for the tractors.

The useful service life of a tractor-trailer is frequently estimated to range from 8 to 10 years. Using the shorter service life, as was done in the rail analysis, annual depreciation of the straight purchase price over 8 years is $96,875. Assuming again, as was done in the rail analysis, that the equivalent of 75 percent of these charges needs to be added to account for interest, financing costs, and return on investment, the annual cost of establishing the fleet is $169,531.

Thus, if the fleet would make one trip per year, i.e., move 1,000 tons, the total investment cost would amount to about $170 per ton. At 100 trips per year these costs would drop to about $1.70 per ton, at 200 trips to about 85 cents per ton and at 300 trips to about 56 cents per ton. These calculations show that the costs of a truck fleet are appreciable if the rigs are underutilized. Operating costs are as a rule classified into two types: running or road costs and driver wages. Driver wages have, to some extent, the same characteristics as running costs. For hauls of more than 50 miles one-way, the driver's pay is set as a rule at a fixed number of cents per mile. Today the driver cost amounts to about 14 cents per mile or $28 for 200 miles which, at a payload of 20 tons, amounts to $1.40 per ton.

The running cost consists of fuel, tires, lubrication, and maintenance. In general these costs vary in direct proportion to the distance traveled and therefore are constant per mile.

The running cost total also adds up to 14 cents per mile or $1.40 per ton. The fuel component is calculated at five cents per mile (25 cents/gal. and 5 mi./gal.) The tire cost, including 18 tires per rig, is calculated at 2 cents per mile. Lubrication and maintenance is 7 cents per mile.

Thus, the total direct operating cost is $2.80 per ton for a 200-mile trip. Assuming maximum utilization of the equipment, i.e., in this case 300

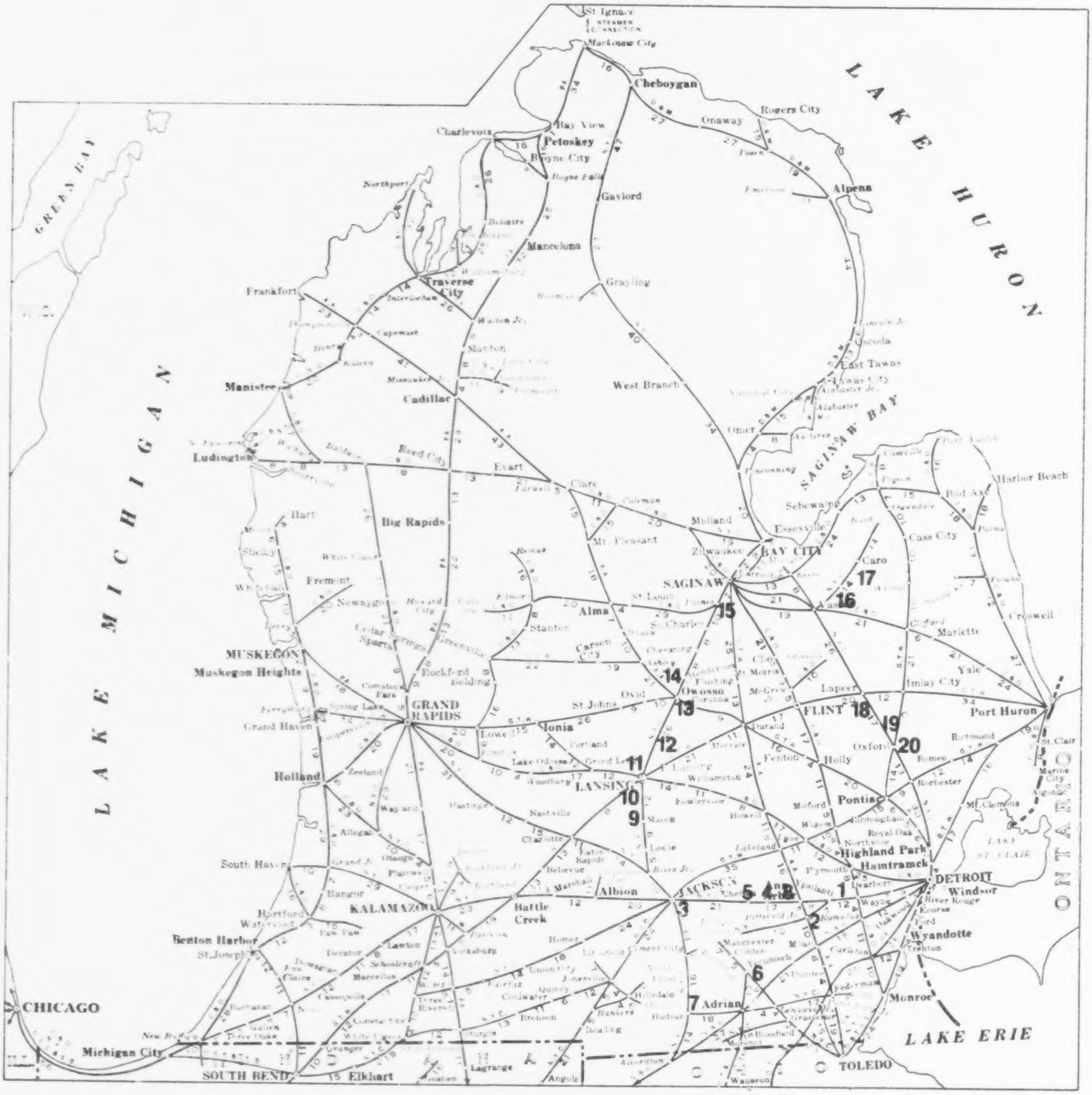
LAKE HURON
LAKE MICHIGAN
LAKE ERIE
ONTARIO
GREEN BAY
SAGINAW BAY
LAKE ST. CLAIR
St. Ignace
Mackinaw City
Cheboygan
Onaway
Rogers City
Alpena
Charlevoix
Petoskey
Bay View
Boyne City
Northport
Gaylord
Mancelona
Traverse City
Frankfort
Grayling
Manistee
Cadillac
Manton
West Branch
Oscoda
East Tawas
Ludington
Reed City
Evart
Clare
Harbor Beach
Hart
Big Rapids
Mt. Pleasant
Midland
Bay City
Sebewaing
Essexville
Zilwaukee
Saginaw
Caro
Cass City
Fremont
Newaygo
Alma
St. Louis
Stanton
Croswell
Marlette
Muskegon
Muskegon Heights
Grand Haven
Spring Lake
Grand Rapids
Rockford
Belding
Greenville
Sparta
Ionia
Lowell
St. Johns
Owosso
Ovid
Flint
Lapeer
Imlay City
Yale
Port Huron
Holland
Zeeland
Lansing
Grand Ledge
Williamston
Fenton
Holly
Oxford
Romeo
Richmond
Rochester
Mt. Clemens
Pontiac
Birmingham
Royal Oak
Highland Park
Hamtramck
Detroit
Windsor
Milford
Howell
Mason
Charlotte
Hastings
Nashville
Eaton Rapids
Allegan
South Haven
Kalamazoo
Battle Creek
Marshall
Albion
Jackson
Ann Arbor
Ypsilanti
Plymouth
Dearborn
Wayne
Romulus
River Rouge
Ecorse
Wyandotte
Trenton
Monroe
Toledo
Adrian
Tecumseh
Hillsdale
Coldwater
Sturgis
Three Rivers
Vicksburg
Schoolcraft
Paw Paw
Lawton
Hartford
Watervliet
Benton Harbor
St. Joseph
Niles
Chicago
Michigan City
South Bend
Elkhart
Angola
Hudson
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FIGURE 22
SURVEY OF POTENTIAL LANDFILL SITES

trips per year, the total cost, excluding overhead, taxes and contingencies, is $3.36 per ton ($2.80 operating plus 56 cents investment cost). Assuming 25 percent as was done in the rail analysis for overhead, base-support, insurance and taxes, and 15 percent for contingencies, i.e., spare units, it is necessary to add $1.34 to the above cost figure. Thus, it is estimated that the cost, within the constraints of this analysis, will be about $4.70 per ton to transport solid wastes by highway trailer over a 100-mile one-way trip.

It must be mentioned that different truck transportation models can be built. For example, if the loading and unloading of the trailers could be done very fast, it might be possible to reduce the number of trailers by one-half. Assuming 300 trips per year and keeping all other variables constant, this would reduce the cost by about 15 cents per ton. However, similar scheduling effects can also be accomplished in rail-haul as well as barge transportation. The actual economic study must be determined using local circumstances and capabilities.

BARGE

Barging via inland waterways is generally regarded as the lowest cost means of transporting bulk materials for many types of haul. In determining the basic equipment needs for solid-waste barging operations, speed of movement becomes very important. The travel speed of barging averages about 6 to 9 miles per hour. Thus, for a round trip distance of 200 miles, the equipment would be enroute from 22 to 34 hours assuming quiet water and no delays due to storm, fog, high water conditions, and waiting at docks.

As a result, it would be necessary to have two towboats or tugboats and at least two barges to allow for the loading and unloading of the materials. The situation changes, of course, if the origination and destination points are located on regularly scheduled barge routes and if it should be possible to effect the daily shipment of the solid wastes by attaching the solid waste barge to a regularly scheduled tow. In such a case, only two barges would be needed.

A barge can be considered a floating container. A standard covered 1,000-ton barge measures about 175 ft. long and 26 ft. wide and has a draft of about 9 ft. This provides about 40,000 cu. ft. of loading space. Such a barge would be used for the transport of 1,000 tons of solid waste at a shipment density of 60 lb/cu. ft. in total, about 34,000 cu. ft. Since a barge of this kind costs about $85,000 and two are needed, the straight purchase price investment is $170,000.

The cost changes considerably if the shipment density of the solid wastes is 20 lb/cu. ft. In this case 100,000 cu. ft. of transport space is needed to transport 1,000 tons. Barge dimensions would be: length 195 ft., width, 35 ft., draft, 9 ft., and superstructure, i.e., upward extension of the basic container, also 9 ft. Such a barge will provide about 105,000 cu. ft. of transport space and its costs are estimated at $145,000 per unit. Thus, the basic barge investment would be $290,000.

The economic service life of barges is often estimated at 15 years which amounts to an annual straight depreciation of about $11,400 and $19,400 respectively. Assuming again that an equivalent of 75 percent of the annual depreciation must be added for interest, financing charges, and return on investment, the total annual charges would amount to $20,000 in the first case and to $34,000 in the second case.

Optimum utilization of each barge would be achieved if it made a maximum of three 200-mile round trips per week or 156 trips per year. The two barges would account, under the best circumstances, for 312 trips per year. As a result, the barge cost would amount to about $64 or $109 per trip or, at 1,000 tons per trip, about 6 cents or 11 cents per ton.

The major cost element in barging is the motive power. If the solid waste barge can be attached to a regular tow the motive power may amount to only 3 to 4 mills per ton mile. At a tareweight of the barge of about 300 tons, the motive power required for 160,000 ton miles (100 miles at 300 tons plus 100 miles at 1,300 tons), costs about $480 or $640 per trip or 48 cents and 64 cents per ton.

The cost structure changes considerably, however, if the motive power is needed only for the solid waste shipments in order to ensure dedicated service, i.e., daily removal of the materials. As indicated above, two tugboats would be needed, and this requirement cannot be reduced because of the travel speed.

The movements of a barge of the size indicated is estimated to require a tugboat of about 600 hp. The cost of such a boat is estimated at about $3.00 per installed horsepower. Thus, one boat costs about $180,000 and the total motive power investment amounts to $360,000.

The service life of tugboats is often estimated to range from 15 to 20 years, similar to the service life for barges. For this present calculation the economic service life is assumed to be 15 years and the annual purchase price depreciation $24,000.

Assuming again that 75 percent of annual purchase price depreciation has to be added for interest, financing charges, and return on investment, the total annual charges amount to $42,000. Operating six days a week, 52 weeks a year, each tugboat would make three trips per week or 156 trips per year, and the two tugboats would handle together 312 trips per year. This leads to a motive power investment cost of about $135 per trip or at 1,000 tons net load a cost of 14 cents per ton.

The size of a vessel's crew is determined by a number of factors including size and power of the boat and degree of automation. It is estimated that a crew of three men would be needed for solid waste operations. Three crews of three men equals nine men per boat plus two cooks brings total employment to 11 men per boat.

At $13,000 per man-year including vacations, retirement, insurance, and related benefits, the annual crew costs amount to $143,000 per 156 trips. This is about $917 per trip, or, at 1,000 tons net load, about 92 cents per ton.

The other operating expenditures are fuel and maintenance. Fuel is calculated at 20 cents per hp. per day; at 600 hp., the figures are $120 per day, $240 per 2-day trip, and 24 cents per ton. Annual maintenance is estimated at 5 percent of investment 5 percent of $180,000, or $9,000 annually per 156 trips. This is about $58 per trip or 6 cents per ton.

As a result, the direct cost for dedicated solid-waste barge service is estimated, within the constraints of this model, to be about $1.47 per ton. Allowing a charge of 25 percent for overhead, taxes, and shore support, and 15 percent for contingencies, brings the total cost to about $2.06 per ton.

In evaluating the cost for rail-haul, barging, and tractor-trailer solid-waste transport, it must be recognized that both rail and barge transport are sensitive to increases in the daily shipment tonnage and increases in shipping distance. An increase in the daily shipment tonnage leads to a reduction in the cost per ton, while an increase in the shipping distance which allows completion of the trip within the two-day period, does not lead to an equivalent increase in cost.

Finally, in comparing the data on barge cost with rail-haul and trucking it must be remembered that the barge cost model assumes, with 156 trips per unit per year, maximum equipment utilization. Reducing utilization of equipment to a level of 108 trips per year by adding extra equipment would increase the cost to approximately $2.70 per ton.

OCEAN DISPOSAL

Oceans offer almost unlimited space for the disposal of solid wastes, *if the wastes can be processed* in a way to prevent harmful or undesirable effects on the marine environment. Solid wastes to be disposed of must be heavy enough to sink and must be put into a form stable enough to prevent floating of any components until they become waterlogged. Waterlogged components, sunk to the bottom of the sea, should be kept there by water pressure; however, additional research into this method of disposal is needed before it can be recommended for use.

Ocean disposal would require the rail-haul segment of the system to terminate at suitable seaside locations. The economics of ocean disposal appear to be attractive, particularly if no site preparation or related operations are required. For a haul distance of about 100 nautical miles offshore and a volume of about 5,000 tons per day, shipping costs have been estimated at $2.25[5] per ton. The shipping could most likely be done in ocean-going, bottom-dump barges or specially designed sea-going vessels. Towing at sea becomes more expensive as the haul distance from shore increases.[5]

[5] *Economic Aspects of Solid-Waste Disposal at Sea*, MIT, Sept., 1970, DB195225

CHAPTER 4

SANITARY LANDFILL OPERATIONS

As previously noted, this study contemplates the use of sanitary landfill as the means of disposal. The sanitary landfill is a proven process, can handle large volumes of wastes, is relatively inexpensive, and can be rapidly implemented. This chapter gives the basic operational requirements for rail-haul sanitary landfills, outlines the types of sites potentially available, and presents some of the major cost elements to be considered.

BASIC OPERATIONAL REQUIREMENTS

Existing landfills are not as large as ones which might be realistically considered as part of a solid-waste rail-haul system. The largest system actually operated disposes of 8,000 tons of refuse per day (Fresh Kills, Staten Island, NYC). For comparison, solid-waste rail-haul, as suggested by the network analysis, appears capable of delivering quantities to one site in excess of 10,000 tons of solid wastes per day.

The cost patterns for sanitary landfills reflect, as a rule, economies of scale. The larger the amount of wastes disposed of, the lower the unit cost. As indicated in Figure 23, Sanitary Landfill Operating Costs, 1968, the cost curve drops sharply as the daily disposal volume increases. The costs shown exclude the cost of land and site development. The latter costs may range from a low of 5 cents per ton up, depending upon local conditions. In addition it may be necessary to pay an "in-lieu" tax on a per ton basis to the jurisdiction in which the landfill is situated as a consideration for obtaining site approval.

Sanitary landfill costs are presently quoted in magazine articles and publicly available contracts to range from about 65 cents to about $2.50 per ton of refuse disposed. It should be recognized that these data refer to existing landfills and the disposal of unprocessed not baled or highly compacted solid wastes. The scale of operations in solid-waste rail-haul landfills suggests that perhaps completely different equipment might be used to perform the on-site operations. At an average density of 60 lb/cu. ft. for compressed solid waste, the disposal space volume requirements in 10,000 tons-a-day landfills will amount to about 12,500 cu. yd. daily. At an average material density of less than 30 lb/cu.ft. as found in most landfills of unprocessed wastes, space requirements would exceed 25,000 cubic yards per day.

These data suggest that, for example, in a 312 working-day year and depending upon the in-place density of the solid wastes, from 3.75 million to more than 7.5 million cu. yd. of earth might have to be moved to provide the necessary space. The data suggest that highly compacted refuse will produce considerable disposal cost advantages because of less need of excavation and cover material per ton of waste.

The type of equipment most likely needed for a large scale undertaking has already been developed for the mining industry, in particular surface mining, and for large scale civil engineering projects. For example, a bucket-wheel excavator, capable of moving 8 million cu. yd. of earth per year, operates at about 8 cents per cu. yd. total cost. The cost of a tractor-scraper with a capacity of about 15 bank cu. yd. per haul runs from about 6 to 8 cents total cost per cu. yd. A shovel with a 100 cu. yd. dipper and a 36 million cu. yd. output per year also costs about 5 to 6 cents per cu. yd. despite the substantial increase in performance.

The price of a bucket-wheel excavator is about $2.8 million, a tractor-scraper about $46,000, and a shovel about $8.4 million. The larger investments in equipment presuppose a certain permanency of operations because such units are not easily moved. Undertaking a number of short-term land reclamation projects with the same equipment would increase costs per cubic yard, emphasizing the importance of matching equipment to total system plans.

Rail-haul landfill operations will differ from existing landfills in other respects than size. In most landfills the wastes are brought directly to the disposal point by collection trucks. For rail-haul, the landfill operations must include rail-car unloading facilities and hauling from a rail-head to the disposal point. The type and scope of unloading facilities depends upon the kind of rail car used, time available for unloading, and on the amount, type and condition of the solid wastes transported.

Site engineering is the keystone of good landfill operations. In principle, rail-haul can use all kinds of landfill sites as long as the size of the site is adequate. However, each site has associated environmental problems, and the cost of overcoming them to keep the landfill from degrading the environment is part of the total cost of operation.

Presently used methods of sanitary landfilling might be continued with some modifications. Larger equipment might require a trench 100 to 200 ft. wide

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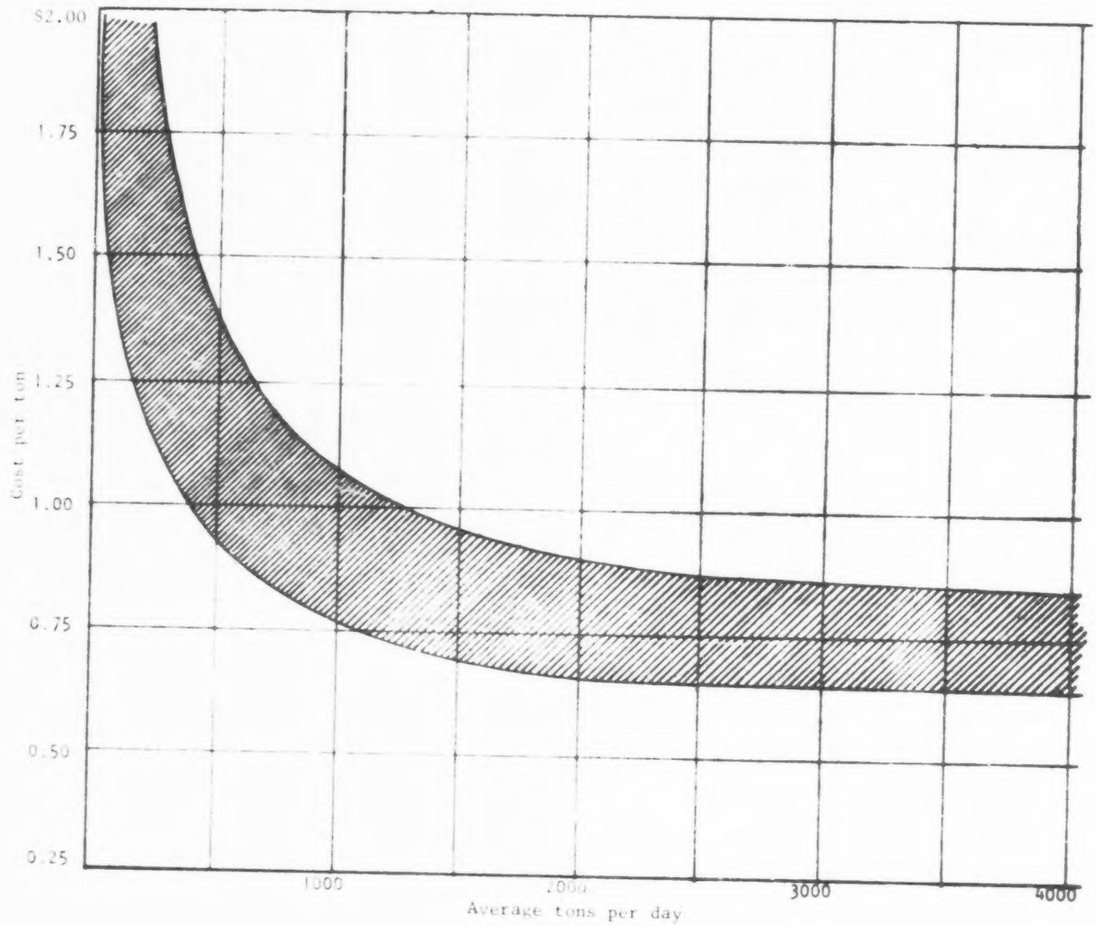


FIGURE 23

SANITARY LANDFILL OPERATING COSTS, 1968

and 50 to 100 ft. deep compared to the more typical 100 ft. wide and 25 ft. deep.

Several possibilities exist for the establishment of large sanitary landfills. Among these are:

1. Pits and Quarries

Pits and quarries, although widely located, do not as a rule have the needed capacity and generally lack sufficient inexpensive cover material nearby.

However, the effective capacity of pits and quarries would be increased substantially if filled with highly compacted refuse. And man-made materials such as urethane foams and asphalt-based substances might be substituted for the intermediate soil cover. Such man-made materials can be porous or nonporous, elastic or rigid, fire resistant, as well as insect and rodent repelling. Some of them have been applied at a cost of 1 to 5 cents per sq. ft. The cost of obtaining and placing suitable cover material might justify such an approach in some situations.

2. Open Pit Mines

Open pit mines are very large but few in number and seldom available. Examples include the iron ore mines in Minnesota and copper mines in Western states. Technological advances are extending the life of such mines by making it economical to mine lower grades of ores. As a result, mine owners are reluctant to forego this often very profitable opportunity by having their pits filled with solid wastes.

3. Scrub Land

Scrub land generally exists to some extent in every state and province and appears to be a potential disposal site. However, scrub land is inoffensive and does not impel people to try to reclaim it. Consequently, it is not likely to be used except in states that have no better alternatives. Use of any scrub land site would depend, of course, on accessibility, on remote location, and on the local soil and water conditions. Conservation and recreation are also important and should be considered.

4. Marshes

A careful distinction must be made in the case of marshes. As a matter of conservation, one cannot arbitrarily use marshes for landfill sites. Many marshes are wildlife refuges or tidal areas that have an important bearing on aquatic life and the fishing industries. In addition, some marsh areas are of considerable recreational value.

There may be marshes which have no such value and may be suitable as landfill sites. As in all other cases, but specifically here, the site selection must take into account the potential for water pollution, flood damage, and the like. A number of good examples do exist where marshes have been used for refuse landfills with highly beneficial results. Nevertheless, great care must be taken in the disposal of solid wastes in marshes.

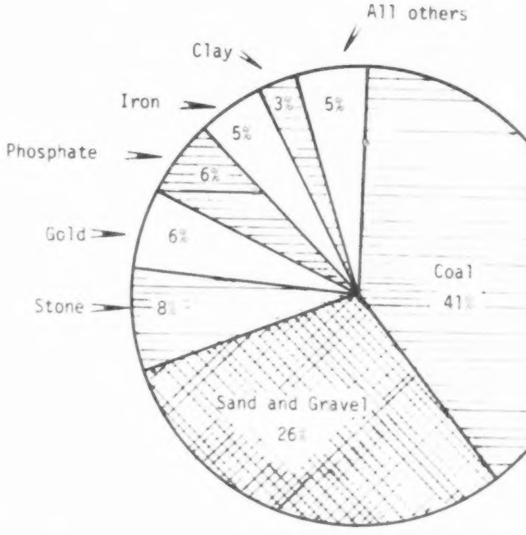
5. Abandoned and Active Strip Mines

Coal as well as ore minerals are strip mined. Coal strip mines may be prime locations for solid-waste rail-haul landfills particularly in the states served by the Penn Central Railroad. Strip coal mines exist in many localities, are accessible by rail, have enormous area, and are generally regarded as having a negative value calling for reclamation.

Consideration of Coal Strip Mines

The U. S. Department of the Interior estimated that in 1965 some 3.2 million acres, or 5,000 square miles of land, had been disturbed by surface mining. Only one-third of this acreage was estimated to have been reclaimed, leaving two-thirds, or roughly 2 million acres, requiring reclamation. Although it is difficult to estimate the annual increase in the acreage disturbed by surface mining, the figure cited for 1964 is approximately 150,000 acres.

Figure 24 indicates that about 41 percent of the land disturbance is caused by the surface mining of coal. Sand and gravel, with 26 percent of the total, represent the second largest commodity. In the overall, the mining of seven commodities accounts for about 95 percent of the total land disturbed by surface mining.



Total = 3.2 million acres

Source: U. S. Department of the Interior

FIGURE 24
PERCENTAGE OF LAND DISTURBED BY SURFACE MINING OF VARIOUS COMMODITIES

The amount of coal mined by stripping increased by about 9 percent between 1965 and 1966, from approximately 165 million tons to approximately 180 million tons. *Coal Age* magazine forecasts that by 1985 the production of bituminous coal by stripping will increase to a minimum of 380 million tons and a maximum of 520 million tons. This is roughly two to three times the present level of production. Thus, active or abandoned coal strip mines appear to offer ample potential sites for the disposal of solid wastes for many years into the future.

Although the total number of strip mines is less than that of underground mines, the productivity, in terms of average output per man per day, is twice as much. This fact is responsible to a great degree for the significant growth in coal mining by the strip method. Due to the rising costs of mining operations, it can be safely assumed that those methods which have high productivity will also have a continued growth. Compared in terms of averages for the total United States mines, underground mines have an average output per man per day of about 14 tons and strip mines of about 32 tons.

Furthermore, the selection of coal strip mines for consideration within the context of solid-waste rail-haul appears to be supported by the geographical location of the mines. In terms of actual production, states east of the Mississippi accounted for 95 percent

TABLE 31
MAJOR COAL PRODUCTION ACTIVITIES BY STATE

States East of Mississippi River	Total Coal Production (Deep, Auger & Strip) 1967 Tons (MM)	Number of Bituminous Coal and Lignite Mines, 1965	States West of Mississippi River	Total Coal Production (Deep, Auger & Strip) 1967 Tons (MM)	Number of Bituminous Coal and Lignite Mines, 1965
Alabama	15.2	206	Arkansas	0.3	8
Illinois	65.7	90	Colorado	5.4	79
Indiana	18.0	61	Iowa	1.0	28
Kentucky	96.3	1,827	Kansas	1.2	6
Maryland	1.4	69	Missouri	3.8	16
Ohio	45.7	417	Montana	0.4	13
Pennsylvania (Anthracite)	11.6	N.A.	New Mexico	3.6	8
Pennsylvania	79.0	1,140	North Dakota (Lignite)	4.0	29
Tennessee	7.3	230	Oklahoma	0.8	15
Virginia	37.9	1,271	Utah	4.5	31
West Virginia	152.2	1,660	Washington	0.06	5
			Wyoming	3.7	14
TOTAL:	519.0	6,971		30.0	252

Sources: Keystone Coal Buyers Manual — 1968. Minerals Yearbook, 1966, U.S. Bureau of Mines.

of the total coal produced in 1967, or some 549 million tons. States west of the Mississippi accounted for only 5 percent, or approximately 30 million tons. The states of Kentucky, West Virginia, Virginia, and Pennsylvania rank highest in the total number of operative coal mines within their borders. Table 31, Major Coal Production Activities by State, indicates the total coal production as well as the number of mines by state.

Thus, the geographical distribution of the coal mines is favorable for solid-waste rail-haul since a significant share of the nation's highly urbanized areas is found east of the Mississippi An analysis of the coal production activities, by states, indicates that mining operations are found either in or close to most industrial states.

Reclamation of Abandoned Strip Mines

Disposal in abandoned strip mines might be considered a special type of sanitary landfilling. Strip mining appears to completely disrupt underground water movement, and causes unnatural and unpredictable mixtures of soil types as well as disruption of the surface water. Thus, the cost of sealing, drainage, and collection and treatment of leachates must be evaluated during site selection.

One disposal opportunity is provided in strip mines by the abandoned last trench, although ground water problems might be greatest at this point; another is found in the gaps between the spoil banks. This latter opportunity blends directly into the reclamation requirements of many states and would help the owners defray their reclamation costs. In a completely different approach, the possibility of working abandoned strip mines backwards offers especially attractive solid waste disposal opportunities.

The reclamation of land is expensive. A survey by the U. S. Department of Interior indicates that in 1964 it cost about $302 per acre to reclaim land disturbed by area strip mining. Today, the same job might cost $450 to $500 per acre. Including planting and contouring, the reclamation cost could range as high as $1,500 per acre. Thus it appears quite safe to estimate a cost of $800 to $1,000 per acre for the reworking of abandoned area strip mines even though the land will be worth only $100 to $200 per acre after reclamation. Using these example figures, solid waste disposal could produce a benefit of $900 per acre.

This value per acre must, of course, be correlated to the stripping depth. A few years ago a stripping

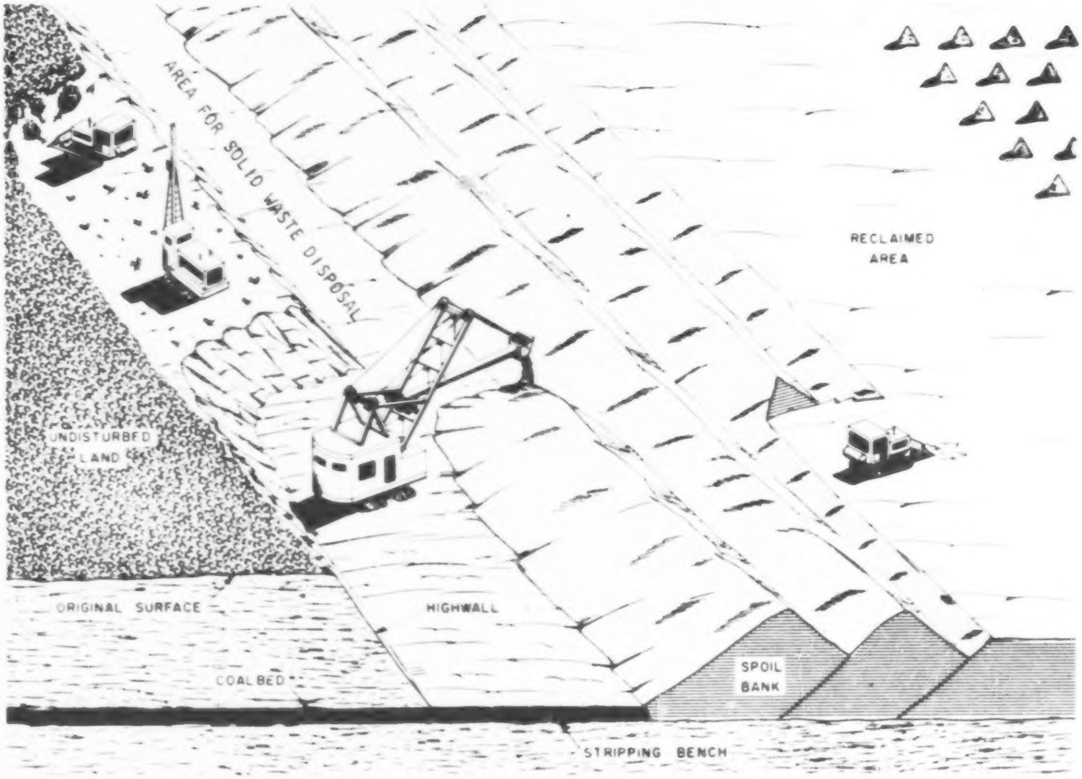


FIGURE 25

OVERVIEW OF ACTIVE STRIP MINE OPERATIONS

depth of 55 ft. was considered a generally accepted maximum. Almost without exception that depth has been increased today to 80 ft. and in several instances 100 ft. Thus, the utilization of abandoned strip mines is primarily an earthmoving venture akin to normal sanitary landfill operations.

Disposal in Active Strip Mines

Introducing solid waste disposal into the operations of an active strip mine would add little or no cost to the mine operation and eliminate the costs of providing waste disposal space and cover material.

Basically, two methods of strip mining are utilized. The first is area stripping, which consists of digging a series of parallel trenches in relatively flat or rolling terrain. The spoil material is placed in a previously made cut, and the mine then resembles the ridges of a washboard with an open trench where the last cut was made.

The second method is contour stripping, which consists of digging around a hillside in steep or mountainous country. This creates a shelf bordered on the inside by a wall that may be as high as 100 feet and on the outside by a rim with a steep outslope covered by loose spoil material.

In this study, the investigation of the feasibility of solid waste disposal in active strip mines concentrates on area strip rather than contour mine operations. This choice avoids the multiple moving and handling costs involved in contour mining. An example of area strip mine operations is illustrated in Figure 25, Overview of Active Strip Mine Operations.

ADDITIONAL CONSIDERATIONS

1. Enhancement of Topography

The large amounts of material which would be involved in rail-haul systems offer opportunities for substantial topographical engineering. Waste materials might be used to build hills in level areas to develop recreation complexes for year-round leisure time activities.

Off-shore islands might be created or existing land enlarged by filling parts of large bodies of water. In both cases, proper dyking and sealing are necessary to avoid water pollution. Such costs might not be prohibitive at a large volume disposal site. Moreover, a substantial body of relevant knowledge and experience is available from coastal land reclamation efforts in Germany and the Netherlands.

2. *Land Reclamation*

The potential for land reclamation may be an important consideration in site selection. Substantial land reclamation might be accomplished by rail-haul solid-waste disposal with no significant costs incurred for the reclamation itself. Furthermore, substantial land reclamation could be accomplished within a very short period of time.

Completion time is highly significant. There is a natural reluctance to undertake long range projects in which the costs become visible from the start while results do not appear until years later. For example, by concentrating huge quantities of fill, the time needed for large reclamation projects might be cut down from, say, 7 or 8 years to 1 or 2 years. Thus, in connection with land reclamation, a demand for rail-haul solid-waste disposal operations might actually arise in many places once the merits of the approach have been demonstrated.

SANITARY LANDFILL OPERATIONS

The functional profile of rail-haul sanitary landfill operations is relatively simple. It involves a. unloading of the rail cars, b. transport of the materials to the point of disposal, and c. disposal, including the preparation of the disposal space and suitably covering the exposed surface. To carry out these operations requires basic site facilities such as railroad spurs and access roads.

The nature of these functions varies, however, with the size and configuration of the site, the time available for retention of the train at the site, the waste tonnage and volume, and particularly the state of the delivered materials, i.e., unprocessed, shredded, or baled. In addition, the carrying out of the functions will vary with climatological conditions, e.g. ranges of temperature, wind velocities, and rainfall.

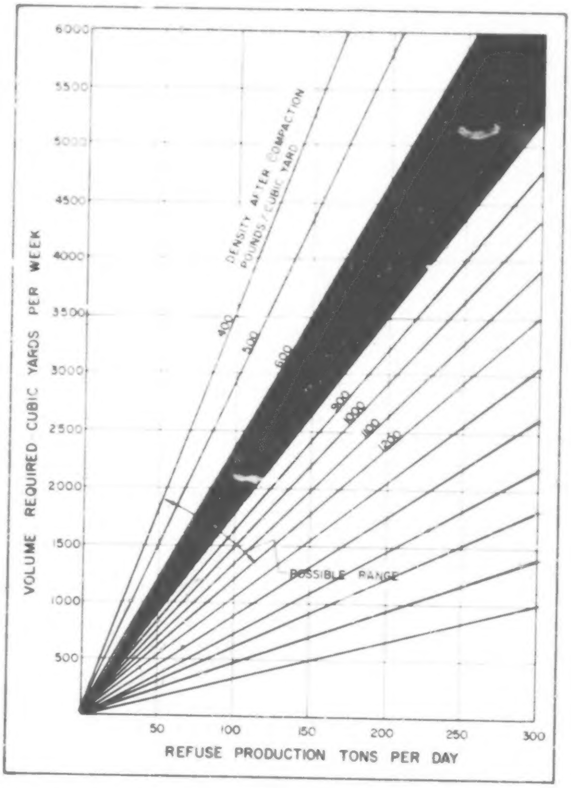
Many models of rail-haul landfill operations could be constructed. For this investigation it was assumed that:

1. the landfill is operated for one 8-hour shift per day which, of course, does not have to represent a 9 a.m. to 5 p.m. time period of the day;
2. the landfill is operated 6 days per week;
3. the train may stay for 8 hours on the landfill site;
4. the landfill will initially handle at least 1,000 tons per day;
5. the on-site traffic conditions would allow a travel speed of up to 20 mph.;
6. the site is exposed to intermittent high winds; and that
7. the distance from the rail-head to the point of disposal averages 4 miles one-way.

Given these conditions, the unloading and transport of the materials would have to be performed "under cover" to prevent blowing paper unless the wastes are containerized or suitably baled.

The space requirements depend upon the compaction achieved at the point of disposal at the time of disposal, i.e., before settlement. A graph, Figure 26, Volume Requirements for Sanitary Landfills, published in the February 1970 issue of Public Works magazine, suggest that, in existing landfills, the density of the materials after placement and compaction ranges from about 600 to 800 lb/cu. yd. (22 to 30 lb/cu. ft.)

However, generally the bulk density for domestic



(Range above 1,200 lbs/cu.yd. added by Karl W. Wolf.)
Source: *Public Works*, February 1970.

FIGURE 26

VOLUME REQUIREMENTS FOR SANITARY LANDFILLS waste compacted in-place is 800-1,000 lb/cu.yd. Other materials which commonly are handled at a disposal site include ash residue 2,000 lb/cu. yd.; bulky waste 540 lb/cu. yd.; stumps 270 lb/cu yd.; dewatered sludge 1,534 lb/cu. yd., and liquid at 1,620 lb/cu. yd. If domestic waste is used as a base, then bulky waste and stumps are 44 percent and 370 percent respectively more expensive to dispose of. Thus the economics of size reduction for such wastes should be evaluated for savings in both the rail-haul and the landfill operation.

Preliminary results of landfilling shredded refuse, conducted at Madison, Wisconsin, suggest an in-place density of the wastes at the point of disposal ranging from 900 to 1,100 lb/cu. yd. (33 to 41 lb/cu. ft.). In contrast and based upon the high-pressure baling and compaction demonstration project, it can be conservatively estimated that the in-place density of baled refuse will range from 1,500 to 1,800 lb/cu. yd. (55 to 67 lb/cu. ft.)

COST ESTIMATES

Present sanitary landfill experience, as documented in journals, magazines, and consultant reports, suggests generally that sanitary landfills can be operated inexpensively, without nuisances, and in many different types of terrain.

Specific costs depend upon many variables, including the price of land, labor, and machinery as well as the number of hours the site is open, the terrain, soil conditions, and the space utilization, i.e., the initial in-place density of the materials disposed of. As a result, an analysis such as this, dealing with general benchmark costs must utilize general data inputs and add or subtract cost elements not represented in the general base.

1. Normal Sanitary Landfills

Since rail-haul systems can use all types of existing sanitary landfills of sufficient size, the cost of operating landfills may be an input for estimating rail-haul landfill cost. It must be remembered that these are point of disposal, site preparation, and maintenance costs. They do not include transport of the wastes or loading or unloading costs.

As summarized in Figure 23, landfill cost in 1968 ranged from about 88 cents to $1.32 per ton for 1,000 ton/day operations. Allowing for inflation at a cost increase of 8 percent per year for the four year period the present cost can be estimated at $1.20 to $1.80 per ton. These costs represent standard landfill operations with compacted densities of up to 1,000 lb/cu. yd.

If in a broad sense the same type operations are necessary to run a site, but the in-place density of the material is doubled as for high-pressure baled solid wastes, the costs would be reduced by one-half to about 60 cents to 90 cents per ton. Other savings could result from, for example, the elimination of the on-site compaction and the greatly reduced point-of-disposal material-control cost. Thus, from only a landfill operations point of view, it is possible to value the effects of high-pressure solid waste baling at 60 cents to 90 cents per ton, which is in addition to the savings in transportation.

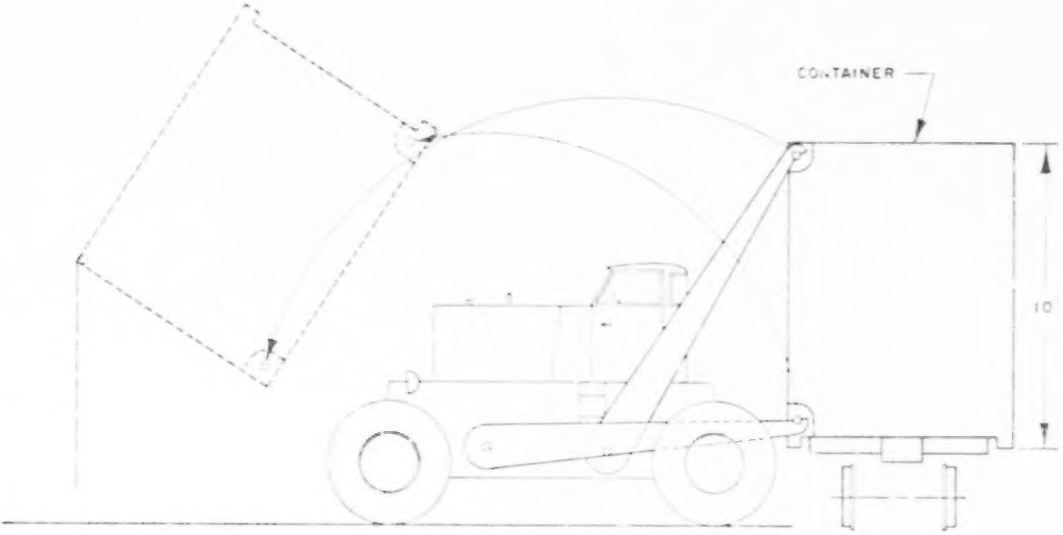
The unloading of the rail cars is assumed to be performed at an even rate. At 1,000 tons per 8-hour shift and an effective working time of 7 hours, allowing 1 hour for coffee break and lunch, the unloading rate is 145 tons per hour.

Unloading operations vary, as indicated previously, with the rail-haul system configuration. Containerized and baled wastes can be unloaded directly from the rail car by an off-the-road fork-lift truck akin to equipment used in the lumber industry. In this case, only a ramp is needed. The fork-lift truck could either transport the wastes to the point of disposal and dump or place them, or it could load the wastes on trailers for transport to the disposal area.

For this analysis it is assumed that the wastes would come in 40-ft. containers, each containing on the average 25 tons, as shown in Table 22. The fork-lift truck would carry an identical amount of baled solid waste per trip. Thus a 30-ton fork-lift truck will be used for the analysis. Figure 27, Mobile Container Carrier and Dumper, shows the container in both the carrying and dumping position.

The average travel speed would be 20 miles per hour or 3 minutes per mile. Thus an 8-mile round trip would require 24 minutes of travel time. Allowing 3 minutes at each end for pick-up and dumping or placement, the total fork-lift working time is estimated at 30 minutes per trip or two trips per hour.

A 30-ton off-the-road fork lift truck costs about $50,000 or about $6,250 per year in straight depreciation for 8-year service life. At 312 days per year and 7 hours per day the annual working time amounts to about 2,184 hours and the straight depreciation would cost $2.86 per hour. Allowing the equivalent of 75 percent of that amount for interest, financing charges, and return on investment, the cost of owning such a fork-lift truck can be estimated at $5.00 per hour. The hourly operating costs are estimated as follows:



Source: Penn Central Transportation Company

FIGURE 27

MOBILE CONTAINERS CARRIER AND DUMP

a. operator ($10,900/year)	$ 5.00
b. fringe benefits @ 25%	1.25
c. fuel and lubrication (12 cents/mile)	2.00
d. off-highway tires (25 cents/mile)	4.00
e. repairs (20 percent of total investment)	$1.05
Total	$13.30

Thus, the fork-lift truck owning and operating costs total $18.30 per hour or, at a performance of 46 tons per hour, about 40 cents per ton.

As a result, allowing 15 percent for contingencies (the overhead costs are already covered in the landfill base cost), sanitary landfill, when used in conjunction with rail-haul is estimated to cost, in round figures, from about $1.85 to $2.55 per ton for loose refuse. Similar landfill using high pressure baled solid waste, are estimated to range, in round figures, from about $1.15 to $1.45 per ton.

ACTIVE STRIP MINES

The disposal of solid wastes in active area coal strip mines is treated as a special case of sanitary landfilling because two operations must be combined.

Moreover, the cost structure of each area strip mine is a unique case, subject like sanitary landfilling to many local variables. These include the amount of stripping that needs to be done, overburden soil conditions, length of haul, demands on the roads that have to be built, coal yields, and the number and types of trucks that can be used.

Nonetheless, it is necessary to gauge in general terms the cost structure of area coal strip mines. Ten major cost centers are identified in Table 32, General Distribution of Revenue Area, Coal Strip Mines by Major Cost Center.

All of the cost items listed in Table 32 are incurred regardless of whether or not solid waste disposal is carried out. Solid waste disposal in active strip mines will affect only a selected number of cost centers.

The cost elements that *could* be affected are:

1. haulage by truck, if mine trucks are used to carry solid waste in a return-haul arrangement,
2. roads, if the solid waste traffic is of such a magnitude that it requires additional roads or impairs the service life of existing roads;
3. supervision on site;
4. certain noncontrollable expenses such as insurance and taxes;
5. general overhead and perhaps certain royalties; and,
6. profit before taxes.

The impact of solid waste disposal on these cost items, varies from item to item depending upon the circumstances. In principle, the solid waste disposal in active strip mines must be organized in a way that will not impair the mining operations. It generally will be necessary to give preference to the mining requirements.

TABLE 32

GENERAL DISTRIBUTION OF REVENUE, AREA COAL STRIP MINES BY MAJOR COST CENTER

Major Cost Centers	Percent of Total Revenue*	Cost Range Per Ton
1. Stripping of overburden	35-45%	$1.57-2.02
2. Coal loading, preparation prospect drilling	5-10%	.23- .45
3. Haulage by truck	3-10%	.15- .45
4. Roads	0.5%	.03
5. Supervision on site	1-2%	.05- .10
6. Land reclamation	0.5%	.03
7. Noncontrollable expenses, e.g., UMWA welfare, taxes, insurance	10-15%	.45- .73
8. Depreciation	15-20%	.73- .90
9. Royalties, general overhead	5-10%	.23- .45
10. Profit before taxes	8-10%	.36- .45

*Total revenue, or mine realization, in 1969 was about $4.50 per ton.

Finally, in reviewing the cost center implication, it must be recognized that profit, before income taxes, is most important in terms of any company's interest. This profit might be increased by either: a. direct royalty type payments, or b. sharing of the general cost incurred in the operations of a mine, or c. a combination of both approaches. The opportunity for the disposal of solid wastes in active strip mines depends on its economic attractiveness.

The elements of solid waste disposal in active strip mines are, in principle, identical to those found in normal rail-haul sanitary landfilling. They require:

1. transfer of the wastes from the rail car,
2. haulage to the point of disposal, and
3. final deposition of the wastes.

Thus, the previously presented data for rail-haul sanitary landfilling may be used in a selective manner. If mine vehicles are not used for the waste transportation, then only the unloading and transportation data as previously given apply. If the wastes are covered in parallel with the removal of the overburden, then point-of-disposal costs will be minimal.

As a result, the initial cost may be as low as 40 cents per ton. Allowing again the equivalent of 25 percent of these costs for overhead, 15 percent for contingencies, and another 10 percent for foreman-type supervision ($12,000/year), the total cost could be estimated as low as 60 cents per ton.

The cost of disposing of solid wastes in active strip mines changes if the existing on-site transportation equipment can be used. Haulage might be in a return haul by a mine railroad or mine trucks. Conveyors, inclined skips, and pneumatic and hydraulic pipe lines also are used in mines for on-site transportation; however, they are excluded from the present considerations because they do not allow for return haul.

The haulage of the wastes by truck appears to be almost universally applicable in mines. Truck transport can follow the disposal face and change capacity easily.

In applying on-site mine trucking costs, it is necessary to ascertain the underlying capacity, speed, and length of haul. Statistics from the U.S. Bureau of Mines show that the average haul from the coal loader to the tipple is 4.6 miles. Furthermore, conservative estimates by mine operators suggest that it is realistic to assume an overall on-site speed performance of 20 mph. In this assumption, speed differentials are averaged out for most of the on-site conditions encountered. Thus the basic on-site transport condition corresponds well to the basic landfill model previously described.

The net load capacity of mine trucks varies widely. The commonly used trucks are capable of carrying from 30 to 100 tons of pay load per trip. New equipment utilizing a tandem trailer combination is designed to carry 150 to 250 tons of material. Using mine trucks to transport solid waste requires the wastes to be highly compacted. To move unprocessed materials at an average density of 600 lb/cu. yd. would, for example, require a 30-ton truck to provide space capable of containing at least 100 to perhaps 120 cu. yd., much larger than normal or practical.

The following conservative mine haulage example is given to indicate the potential order of magnitude in the economics of on-site solid waste transport by return haul. The example is based on a 35-ton, 35 cu.-yd. truck, a $75,000 purchase price, a 5-year depreciation period, 2,500 working hours per year, a 4-mile one-way trip, only 20 mph. speed, a 6-minute waste loading and unloading time for each trip, a material density of about 0.8 tons or 1,600 lb/cu. yd., and an additional burden of 5 minutes per trip to account for loss of truck availability in the coal haulage.

Within the above context, the truck is capable of moving only 23 tons of baled solid waste per trip due to volume limitations. The round trip time can be calculated at 41 minutes of which 23 minutes are for the solid waste haul (6 minutes loading, 5 minutes burden, 12 minutes travel), and 18 minutes for the coal haul (6 minutes loading and unloading, 12 minutes travel).

The specific estimates for the normal operation of the mine truck are contained in Table 33, Cost of Owning and Operating a 35-Ton Mine Truck.

Based on these computations, it would cost about 42 cents to move one ton of solid waste 4 miles. The estimate is based on a truck cost of about 42 cents per minute with the truck charged with 23 tons for 23 minutes. If the 20 mph. speed of the example could be increased to an average speed of 24 mph. as indicated by Table 33, the unit cost would be considerably reduced.

Waste haulage represents only one part of the total disposal cost. Additional costs are incurred in the loading of the mine truck. Thus, compared with the estimated cost of 40 cents per ton for the use of an off-highway fork-lift truck it can be concluded that solid waste disposal in active strip mines should be performed with haulage equipment made to order for the solid-waste transport function. This would alleviate many organizational problems in the mine operation.

In summary it appears feasible to dispose of baled solid wastes in active area strip coal mines at a cost of perhaps less than $1.25 per ton. However, the specific implementation of the disposal process in active strip mines also will depend upon the amounts of wastes handled per shift, number of shifts per day, trade-off implications with respect to the train waiting time, and the on-site haul distance. The above analyses suggest that on-site haulage might constitute both the major disposal cost element and the primary cost variable.

TABLE 33
COST OF OWNING AND OPERATING A 35-TON MINE TRUCK (Industry Averages)

Cost Item	Hourly Cost
1. Fuel and lubrication ($0.10/mile, 24 miles/hour)	$2.40
2. Repair ($0.10/mile, 24 miles/hour)	2.40
3. Tires for off-highway duty ($0.15/mile, 24 miles/hour)	3.60
4. Depreciation/Purchase price (five-year service life)	6.00
5. Interest, Financing charges, Return on investment (75% of purchase price depreciation)	4.50
6. Operator (including 25% for fringe benefits)	6.25
TOTAL	$25.15/hour

Source: IIT Research Inst. and Handbook of Mining

CHAPTER 5

ADMINISTRATION

REGULATORY ASPECTS OF SOLID WASTE DISPOSAL

Broad jurisdiction over the regulation of solid waste disposal, is vested in the 50 states; although many have delegated certain powers and authority in this field to local units of government. An inquiry was sent to each state to ascertain the nature of their organization for handling such responsibilities, the extent of their powers and the various procedures employed. Responses received from officials of 41 states[6] provide the basis for development of this chapter.

Organizational Placement of Solid Waste Management

In 20 of the responding states only a single agency was named as exercising solid waste management responsibilities. In one state (Ohio) a separate water pollution agency was specified, in two (Colorado, New York) a separate one for air pollution, and in six (Alabama, California, Florida, Missouri, Utah, and West Virginia) the primary solid waste agency was flanked by a pair, for control of air pollution and water pollution respectively. Among "related agencies" named as having some solid wastes responsibilities are:

Forestry agencies in California and Pennsylvania;

Natural Resources agencies in Delaware, Michigan, Nevada, North Dakota, Washington, and West Virginia;

Transportation agencies in New Jersey and Pennsylvania;

Public utility regulatory agencies in Nevada, New Jersey, North Dakota, Pennsylvania, and Washington;

Planning/community affairs agencies in Idaho, Pennsylvania, Vermont, and Washington;

Commerce/industry agencies in Michigan and Pennsylvania;

Fish and game agencies in Nevada and Pennsylvania; and

Highways agencies in Utah and West Virginia.

Kentucky responded most perceptively that, in addition to the Division of Solid Waste in the State Health Department, "49 agencies have some power in the solid waste field, ranging from very minor to great control. In talking to other states, [we] have found their powers are splintered just about as widely." By way of further explanation the response notes certain enforcement powers concerning animal and food processing wastes in the agriculture department, mine wastes in the mining department, timber wastes in the natural resources department, fish kill wastes in fish and wildlife departments, and litter in highways and parks departments—not to mention still other powers in the state police.

The date and mode of establishment of reported solid waste agencies is set forth in the tabulation which follows.

It will be noted that three-fourths (30) of the principal agencies were created by statutes which were enacted within the past 6 years in two-thirds (14) of the 21 states for which date of enactment is given. Eleven came into being by executive or administrative order, eight of them since 1964. All the "related agencies" reported were created by statute; of the 21 for which dates were supplied, half (10) came into being within 5 years 1965-69 and six more in the single year 1970.

Of the 20 states reporting one single agency

	Principal SW Agency Created: By Statute	By Governor	By Board of Health	Sub Total	Related Agencies By Law	Grand Total of all
1 year 1970	6	1	1	8	6	14
5 years 1965-69	8	5	1	14	10	24
10 years 1955-64	1			1	2	3
10 years 1945-54	4		1	5	2	7
pre-1900	2			2	1	3
Year unspecified	9	1	1	11	10	21
TOTAL	30	7	4	41	31	72

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[6] Missing were reports from Connecticut, Illinois, Indiana, Louisiana, Massachusetts, New Mexico, North Carolina, Texas, and Wisconsin.

involved in solid waste management, half (10) of those were created in the 5 years 1966-70 and half (5) of those within the last 2 years. The latter group is composed of Alaska, Georgia, Hawaii, Kansas, and Rhode Island.

Structurally the solid waste agency is located within the state health department in 25 of the 41 reporting states and within a "health and welfare" department in eight others. In these 33 cases the unit is known as the division, bureau, or section of:

Environmental health in eight cases,
Environmental sanitation/engineering in five,
Sanitation/sanitary engineering in five, and
Solid waste managmenet in eight, with two incorporating vector control.

Particularly designated pollution control agencies are reported by the remaining eight states, as follows:

Arkansas–Pollution Control Commission
Minnesota–Pollution Control Agency
New Jersey–Department of Environmental Protection
New York–Department of Environmental Conservation
Pennsylvania–Department of Environmental Resources
South Carolina–Pollution Control Authority
Vermont–Agency of Environmental Conservation
Washington–Department of Ecology

The functions handled by the state solid waste agencies take the general pattern of establishing, promulgating, and enforcing standards and regulations. Somewhat fewer help local jurisdictions with planning and techniques. Very few provide financial assistance and virtually none operate solid waste facilities. The reported distribution is as follows:

	Principal Agency (41)	**Related Agencies**
Promulgates regulations	38	30
Requires conformance	34	31
Develops standards	39	18
Assists planning	41	13
Technical assistance	39	14
Reviews local plans	37	15
Financial assistance	7	6
Operates facilities	2	4

General Overview of Problems Likely to Attend Initiation of Rail Haul Disposal of Solid Waste

Briefly summarized in Table 34 are responses concerning the main problems that a rail haul disposal system might present to the 40 reporting states. (Hawaii, is omitted from the analysis which follows.)

The legal and technical aspects were notably of less concern than those of economics and public opinion. A brief recapitulation indicates for each category how many of the 40 responded in the negative, with a mildly qualified negative, or gave no response to the item–and the remainder who posed problem(s) considered to be of some significance.

Problems	**Legal**	**Technical**	**Economic**	**Public Opinions**
None	12	12	3	0
None, but . . .	6	8	4	7
No answer	5	3	3	1
Total negative	23	23	10	8
Problems Cited	17	17	30	32

The legal difficulties alluded to in the overview revolved around zoning legislation (see Kentucky, Michigan, Missouri, and West Virginia), anti-importation laws (see Delaware, Maine, New Jersey, and Rhode Island), and legal barriers in receiving areas (see California, Kansas, Maryland, Nebraska, North Dakota, and Pennsylvania). Lack of regional mechanisms was cited by Florida and the need for operating controls by Michigan and South Dakota.

Comments on technical considerations focused primarily on design and operation of transportation and transfer equipment (see Alabama, Iowa, Kansas, Kentucky, Michigan, Minnesota, New Jersey, New York, Tennessee, Utah, and Vermont). Geologic problems were cited by Florida and Washington and the inadequacy of the railroad systems in Alaska, Idaho, and Utah. New Jersey was concerned about storage in the event of strikes or breakdowns, and New Hampshire about how and where to unload as landfill sites fill up.

While the economic problems cited were much more numerous, they centered on a common core of costs (too high), volume of refuse (insufficient), and economic justification (compared to alternatives).

Public opinion problems concentrate almost wholly on the probability or certainty of adverse reactions in receiving areas, including a need to "educate" the public or provide a good "image" for the operation. How the operating procedures would be carried out would determine the degree of public acceptance, in the opinion of Iowa, Minnesota, and New Hampshire respondents. Opposition on the basis of costs would be anticipated in Arizona, Montana, and Utah–states with a relative plenty of available land and a relative paucity of railroad lines.

TABLE 34

GENERAL PROBLEMS RELATED TO POSSIBLE INITIATION OF RAIL-HAUL DISPOSAL OF SOLID WASTES

State	Of a Legal Nature	Of a Technical Nature	Of an Economic Nature	Public Opinion Nature
Alabama		Transfer & disposal sites, special cars, spur lines	Haul costs & financing	
Alaska		Scant railroad mileage to only a few communities	Cost would be greater than conventional means	Doubt any part of state wants another's refuse
Arizona	None	None	More expensive	None except regarding cost
Arkansas		None if proper planning were done.	Probably not enough waste to warrant rail haul	Against depositing large amounts in this area.
California	Guarantees of performance required. Approval by receiving jurisdiction	None specifically; newly developed systems might have higher costs.	System would have to compete with landfill disposal and guarantee performance	Gain acceptance of local local citizens in area of disposal
Colorado	None	None	None (transfer operations generally more feasible)	Generally, one jurisdiction doesn't want another's wastes.
Delaware	Garbage & household refuse cannot be brought into state	None	None	Possible objections to intercounty hauling in recipient areas
Florida	Florida is "county oriented" and few successful regional efforts exist	High water table reduces availability of proper land disposal sites	Rail network is such that long hauls would be necessary thus increasing costs	Obvious reticence toward disposal sites, especially for waste from a "foreign" source
Georgia	None from a public health point of view	None, as equipment and methodology would have to comply with our rules	None, unless a proposal was considered for a nonurban area	Presently, citizens would oppose disposal of others' waste in their area. Dynamic public information program needed
Hawaii	Rail-haul has not been considered as a means to transport solid waste to date under existing conditions.			
Idaho	None	Not all cities and counties served by railroad	Distances very great; population centers not large enough to warrant	Public would probably object to disposal near them
Kansas	Litigation by recipients to prevent such practices	Littering and escape of wastes en route and at disposal site.	Costs of haul, special handling, transfer from rail-head to disposal site	To overcome "dumping ground" stigma associated with disposal site
Kentucky	Zoning for loading & unloading sites; required permits for disposal	Compaction required to obtain economic local & multihandling at both ends of system	So far economics of system not fully revealed and placed on a competitive basis	Varies widely
Maine	State law basis importing solid waste	None. Maine rail network very extensive	It would be doubtful if Maine would export	Public opinion negative; refer to law cited
Maryland	1970 law to bar rail haul of metropolitan wastes	Most problems have already been solved	Payment of "bounty" charges; specially designed cars	Adverse public opinion has for practical purposes killed the idea
Michigan	Controls for hauling, loading, and unloading rail cars; appropriate zoning	Handling techniques to be employed in transferring waste	Cost comparisons thus far do not appear adequate to support such a program	Public opinion has not yet developed on rail-haul but already a problem on disposal sites
Minnesota	None	Type of rail car, type and nature of volume reduction along R/W, double handling material	Cost of multiple handling construction cost for spur track	Depends entirely on nature of operation, time of trains, if covered, leakage, etc.
Mississippi	None if haul is within state.	None	Not feasible; most land costs reasonable	Would require an educational program
Missouri	Possibly specifically passed zoning laws	None that could not be easily solved	Rail haul would cost more than other methods	Adverse from generators and recipients
Montana	None	None	Much more expensive than other methods available	Public would not favor this because of cost

TABLE 34 (Continued)

State	Of a Legal Nature	Of a Technical Nature	Of an Economic Nature	Public Opinion Nature
Nebraska	Prospective			Much opposition
Nevada				Usual opposition to waste from other areas
New Hampshire	None other than those involved in normal rail haul	How and where to unload because of landfill sites being constantly used up	Might be disastrous as railroads have played smaller and smaller role in state; rather expensive to revitalize them	Unfavorable public opinion might arise out of unsightliness of a trainload of solid waste. If covered, should be O.K.
New Jersey	Pending legislation prohibits importation of solid waste into New Jersey	Receiving & loading facilities, storage of refuse in case of strikes or breakdowns	Construction of facilities at rail heads	For rail haul into New Jersey, tremendous objection; out of state, minor
New York	None. Presently utilizing rail haul to transport spent fuel elements from nuclear reactors	Cannot envision any, providing adequate engineering design of transfer stations & rail haul cars	May not be most economical alternative. Some might arise when more than one rail line involved in given haul	Opposition by residents in area receiving the wastes
North Dakota	Court action to restrain development	None of importance	None, if rail haul were profitable to the hauler	None if initiated by people of the state
Ohio	Probably no major problems	Success of rail haul has not been demonstrated	Extra handling equals extra cost	Public opinion would vary throughout state
Oklahoma	Would require permit	None	Probably not feasible for years to come	Doubtful
Oregon	Insufficient data available to answer			
Pennsylvania	Need county approval	None	Might be dependent on federal or state funding	Would hinge on public image created and health hazard or nuisance
Rhode Island	Illegal to import into state, also illegal into some towns	None	None	Exporters would be for or neutral. Receivers would be opposed
South Carolina	None	Nothing unusual	Not excessive	None if properly handled
South Dakota	Rail-haul concept has not been considered	Competent planning and adequate equipment, and operators unavailable	No areas have enough population concentration to make economically feasible	Opposition, especially to large operation, might be expected
Tennessee	Interstate transportation	Collection at rail center; odor from putrefying waste in transit	Low-cost land will probably make rail haul uneconomical	Some areas will be sensitive about receiving waste from other areas
Utah	None	Many areas far removed from rail facilities	Abundance of open land available for disposal	Adverse
Vermont	When does ownership change? New tariffs?	Containerization and mechanization	Rail charges to pay for waste tonnage needed	Acceptable to have refuse brought in for reuse
Virginia	None	None	None	Overcome local stigma
Washington	None	Available site and adequate trackage	Financing	Considerable negative reactions at first
West Virginia	Zoning and highway beautification	Not great as to ground water protection	Lack of money and ability to raise it locally	Strong resistance to disposal sites
Wyoming	None	None	Prohibitive freight rates	Possibly

Legal Considerations

State laws regulating landfill disposal are in effect in all but five of the 41 reporting states. Alaska has enabling legislation for landfill regulation, and a law is proposed in Georgia; hence only Maine, South Carolina, and Wyoming are evidently wholly without such a statute. Laws governing rail freight transport, as would be applicable to solid waste rail operations, are reported by barely a quarter (10) of the responding states–Iowa, Maryland, Minnesota, North Dakota, Oklahoma, Rhode Island, Tennessee, Utah, Vermont, and Washington. Qualified affirmative responses were also given by Colorado (that the Public Utilities Commission has jurisdiction over proposed revision of services), Kentucky (that health nuisance laws would apply), and Pennsylvania (that general regulation is provided by the state's Solid Waste Management Act).

The responsibilities which the state discharges relative to landfill sites were listed on the inquiry form in eight categories, thus:

Survey available sites,

Hold hearings on sites,

Requires submission of plans for use of sites,

Establish standards of landfill operations,

Check compliance with standards,

Require inclusion of solid wastes disposal plans in local planning,

Provide technical assistance to local agencies, and

Provide financial assistance to local agencies.

All 41 states report providing technical assistance but only a quarter (10) of them provide financial assistance–Delaware, Maryland, Pennsylvania, and Vermont (which are affirmative in all eight categories), plus Florida, Kansas, New York, Ohio, Rhode Island, and Washington. New Jersey reports financial assistance "pending," which will bring that state into all eight categories. The least assumption of specified responsibilities is the reported two categories each in Arizona and Maine and three in Colorado and South Dakota. With "technical assistance" universal, as noted, the other categories are "standards" in Arizona; "survey" in Maine, Colorado, and South Dakota; "checking compliance" in Colorado; and "plans" in South Dakota.

In addition to the itemized eight categories, several states report "other" state responsibilities, including:

Geologic and hydrologic feasibility studies in Alabama,

Assistance in financing demonstration projects in New York,

Reviewing and monitoring solid waste planning and demonstration projects in Kentucky,

Planning, designing, constructing, and operating solid waste facilities under certain conditions in Maryland, and

Educational programs in Nebraska and Vermont.

Legal situations particularly pertinent to initiation of rail haul disposal concern the ability of two or more counties, or jurisdictions in different counties, to enter into implementing agreements. In relation to the disposal of solid waste, 40 reportedly have the authority, with only one (Maine) responding in the negative. In relation to transport of solid waste, four others are also negative–Florida, Idaho, Missouri, and Rhode Island. Wyoming indicated some uncertainty as to powers of its local governments in that regard.

A probably significant legislative tendency to prohibit the "importation" of solid wastes into state or local jurisdictions is noted, even though over 60 percent (25) of the 40 reporting states (excluding Hawaii, inapplicable) answer in the negative and three more are substantially so. Four states now have such prohibitions statewide–Delaware, New Hampshire, Pennsylvania (in reference to mine disposal), and Vermont–and such a law is reported pending in New Jersey. Local governments have the power to enact prohibitory ordinances in California, Kentucky, Maine, Maryland, Minnesota, New Jersey, New York, and Washington.

In addition to statute law, "judicial" law may be applicable to such innovations as initiation of rail haul disposal; hence respondents were asked whether they are aware of any litigation within the state that would relate to the use of land for solid waste disposal purposes. From half (21) of the states the responses were negative; several procedural actions (e.g., condemnation) were cited in California, and actions to abate certain offensive practices (e.g., open burning) or negligent operation were cited from six states. This leaves site selection the evident crux of the matter in the following 13 states.

Georgia – In an action brought by adjacent residents to enjoin the City of Carrollton from operating a sanitary landfill, a Superior Court judge in September 1970 declined to enjoin the operation but did prescribe certain restrictions. The city was enjoined (1.) from polluting the river or the air by burning or dumping and by dumping at all except on their own property, (2.) from dumping at all except when sufficient machinery and manpower are available on the premises for carrying on the proper operation of packing and covering, (3.) from dumping such things as eggs, animal waste, and dead animals unless they are placed in a properly prepared ditch and covered immediately, and (4.) from burying or dumping any waste in such a way as to be unearthed and to pollute either the river or to flow on the property of the other persons in the area. The ruling also imposed a temporary requirement to have some person on the premises at all times to see that the material carried there is properly placed in an area or in a can; it is contemplated that when the operation is "under control" the requirement for keeping somebody on the premises continually would be lifted.

Iowa – The Des Moines Metro Solid Waste Agency selected a sanitary landfill site and secured from the Polk County Zoning Board a "special use permit" which adjacent residents sought to have invalidated. The County Court upheld the zoning board's action and plaintiffs appealed the ruling to the Iowa Supreme Court, whose decision is expected to be handed down in mid-July 1971.

Michigan – Courts have decreed both in favor of and against the use of sites for landfills.

Minnesota – In a May 1971 decision the Olmsted County District Court denied an injunction sought by the Town of Oronoco to prevent the City of Rochester from operating a sanitary landfill within the Town(ship) on land owned by the city and for which a permit had been obtained from the Minnesota Pollution Control Agency. Provisions of an *ex post facto* zoning ordinance of the town were ruled invalid. In another case the Minnesota Pollution Control Agency in 1971 granted the City of Hopkins a permit to operate a landfill within its boundaries, despite its location less than the statutory distance from a municipal well and on condition of periodically monitoring water quality in the vicinity. A companion requirement to construct "an adequate disposal area for toxic and hazardous wastes within said landfill" may be amended to permit the city to provide a portable receptacle for disposal of such wastes prior to transfer to an ultimate disposal site.

Mississippi – Injunction has been used to prohibit use of a site until state standards for landfill were initiated.

Nebraska – The State Supreme Court in October 1970 affirmed a district court denial of injunction sought against an "anticipated nuisance" from proposed establishment of a sanitary landfill in rural Madison County by Community Disposal, Inc., contractor for the City of Norfolk, under license issued by the State Health Department. The Court ruled that "It is generally accepted that a refuse disposal operation is not a nuisance per se but it may become a nuisance in fact as a result of the manner in which it is operated" but that "The burden rests on the one complaining to establish that the use to be made of the property must necessarily create a nuisance." Another site location case is now pending before the State Supreme Court.

New Jersey – A case involving the Hackensack Meadowlands Development Corporation is pending in court.

Ohio – Two sites under same ownership are being stopped pending decisions on local zoning.

Pennsylvania – In 1970 sixteen major cases, involving both municipal and private sites, were settled in favor of the State Environmental Resources Department by court order, stipulation agreement, summary proceedings or preliminary injunction.

Rhode Island – Petitions have been brought in court to prevent the establishment of landfills.

Vermont – A proposed site for a privately operated landfill at Pittsford was approved by the State Environmental Board on the condition that the applicant obtain the approval of the local zoning board; this was denied in October 1970 and the matter is now being appealed in the courts. In another case the Addison Chancery Court in December 1970 denied a request by the Town of Bristol for a temporary injunction against operation therein of a contractor-operated landfill that was sanctioned by the State.

Washington – A proposed 223-acre landfill, to be privately operated to dispose of Seattle wastes, located at the eastern end of Coal Creek south of Bellevue, is currently in vigorous contention. Hearings by the King County zoning examiner began in November 1970 on the site owner's most recent application (the fourth since 1963) for a "dumping permit" required for the landfill operation; after "6 months of testimony" the hearings are now in recess, with a decision expected in September 1971.

West Virginia – Injunctive action was brought when ground water was possibly endangered – and where a road to the site, serving local residents, was considered too weak for trucks.

Technical Considerations

Only one-sixth (7) of the reporting states evidently had adopted a state plan for solid waste management at the time of replying–Colorado, Kentucky, Minnesota, Montana, Oregon, Pennsylvania, and West Virginia. In Idaho and New Jersey the state plan was then completed but not as yet adopted. Practically all the remaining states (28 of the 32) indicated that preparation of such a plan was then in process. Only four states indicated that they neither have a plan nor are at work on one—Alabama, Alaska, Nebraska, and Nevada.

Training programs in relation to solid waste management have been instituted in 18 states as follows:

For state and local officials—Colorado, Florida, Hawaii, Iowa, Maryland, Michigan, Minnesota, Montana, New York, North Dakota, Ohio, Pennsylvania, Vermont, and Washington.

For state officials only—Alaska, Georgia, New Jersey, and West Virginia.

In addition, training for local officials is being planned in Arizona and Georgia.

State surveys of potential disposal sites have reportedly been made by eight states—Colorado, Mississippi, Nevada, New York, Oklahoma, Pennsylvania, Vermont, and Washington. In addition, partial surveys have been made by Alabama, Alaska, South Dakota, and Tennessee. This small total, of only about 30 percent of reporting states, probably means that many state solid waste management agencies have inadequate staff and finances to conduct such a sizeable undertaking.

Master plans for solid waste management that are regionally oriented, rather than of statewide applicability, are reported by a number of states. They are focused upon primary metropolitan areas in Arizona, Colorado, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Oregon, and Virginia. The prime movers organizationally are *councils of governments* in Alabama, Colorado, Michigan, and Tennessee; *planning agencies* in Kansas, Minnesota, Missouri, Oregon, and Virginia; *counties* in Alabama, Alaska (boroughs), Arkansas, California, Michigan, and New York; and *development authorities* in New Jersey, Oklahoma, and Pennsylvania. Interstate agencies are in the Kansas-Missouri and New York-New Jersey Pennsylvania area. Regionally oriented plans are in process in Florida, Georgia, and Maine; they are reportedly under consideration in Delaware and Mississippi.

While practically all of the reporting states have laws regulating landfill disposal, and in most cases check compliance with prescribed standards, only a quarter (10) report having a listing of private firms that are engaged in disposal operations within the state. Those assertedly so equipped are California, Idaho, Kentucky, Maryland, Michigan, Nebraska, New Jersey, Pennsylvania, Vermont, and West Virginia. South Dakota indicates availability of a listing from another source, while Utah notes that there are no such firms within the state.

Recognizing the likelihood that state regulation of solid waste management might entail differing procedures dependent on whether a private entity or a public agency were being regulated, the question was asked: "In what respect does state law require dealing differently with private entities than with public agencies?" Three quarters (30) of the states assert that there are no differences. Wyoming says there is no applicable law, Washington has not yet studied the matter, and Kansas did not reply to the item. The eight indicating some differences do so in the following terms:

Iowa—Private agency must post surety bond with local public agency.

Kentucky—Differences are in the planning role.

Maryland—Authority given for regulating disposal sites "for public use." Court held requirements of law include private disposal operation where wastes are collected from several sources. Whether large corporation can dispose of its own wastes without complying with regulations has not yet been determined.

Michigan—Bonding and fee payments.

Nebraska—Private enterprise is required to post $2,500 bond; governmental entities do not.

Ohio—State law permits local health departments to grant conditional licenses to governmental agencies but not to private owners.

Vermont—Private operators are not exempt on junkyard licenses, screening, and setback from highways.

West Virginia—Private collectors regulated and franchised by state except within municipalities; local governments not regulated.

Economic Considerations

The economic aspects of prospective rail haul operations weigh more heavily in the estimation of respondents than do those of a basically legal or technical nature. As previously noted, three-fourths (30) of them forsee problems in general relation to costs, volume and economic justification.

The prospectively high costs of rail transport, including "financing" problems, are cited by Alabama, Arizona, Kansas, Minnesota, New Jersey, Ohio, Vermont, Washington, and Wyoming.

The likelihood of insufficient generation of waste was noted by Arkansas, Idaho, and South Dakota.

The presumption that rail haul could not compete advantageously against more conventional disposal procedures (often linked to availability of sufficient land for landfill, for example) is advanced by Alaska, California, Colorado, Mississippi, Missouri, Montana, Tennessee, and Utah. Kentucky and Michigan were of the same opinion but stress that presently available cost figures are inadequate to fully appraise the economic justification of rail haul.

In addition, an insufficiency or disadvantageous layout of railroad trackage and facilities was mentioned by Alaska, Florida, Idaho, New Hampshire, New York, and Utah.

The extent of state awareness of local practices and economic facts is not encouraging at the moment, on the basis of questionnaire replies. It is recognized, of course, that many of the agencies are relatively newly established and that comprehension of some of the elements will grow with experience. It has been noted that only about a quarter of the states have surveyed potential disposal sites, and only that proportion have available lists of private disposal firms. Slightly more of them (14) report that a relatively current survey of refuse collection/disposal charges is available — Arkansas, Florida, Kentucky, Maine, Michigan, New Hampshire, New Jersey, New York, Oklahoma, Pennsylvania, South Carolina, South Dakota, Tennessee, and Washington. These are not often reports by the state agency; state leagues of municipalities often conduct such surveys and publish the results.

An admittedly difficult series of requests called for a statement of viewpoints as to "optimum or estimated unit costs" for a. sanitary landfill, b. rail-haul from rail head to disposal site and c. a full system of rail-haul disposal. Nine reported figures for landfill, only three for the other two categories are given in Table 35.

Landfill unit costs cluster around the $1.50-$2.50 mark; the few figures supplied range from $3.00 to $6.00 for rail haul and $5.00 to $8.50 for the complete operation. In the latter two groups the figures are undoubtedly approximations, in the main, based on the landfill figures that tend to be more precise. Probably the three who responded (and the 38 who didn't) would tend to agree with Kentucky's observation that the size of the operation has such great effect on costs that typical costs are not practical.

TABLE 35
OPTIMUM OR ESTIMATED UNIT COSTS (per ton) FOR VARIOUS SOLID WASTES DISPOSAL OPERATIONS

	Sanitary Landfill	Rail Haul to Disposal Site	Full Rail-Haul Disposal
Arizona	$1.68		
California	$2-$4		
Maryland	over $1.50	$3*	$8.50*
Montana	under $2		
Oklahoma	$2-$3	$3-$5	$5-$7
Pennsylvania	up to $2.50	$4-$6	$6-$8
Utah	$1.50		
Vermont	$2.50		
Virginia	$1.50-$2		

*Based on trip of 200 miles one way

Source: APWA Survey of State Agencies

Inquiry as to a scarcity of suitable landfill disposal sites (either generally or in specific areas) brought a mixed response. Only four states (Colorado, Florida, New Hampshire, and Oregon) indicated general *and* specific scarcity; two others (Hawaii and Pennsylvania) indicate general scarcity which evidently includes specifics. Reporting neither general nor specific scarcities were seven states (Kentucky, Maine, Mississippi, Montana, Oklahoma, South Dakota, and Wyoming); from five others (Alabama, Minnesota, Nevada, North Dakota, and West Virginia) a negative general answer evidently applies also to specifics. A majority of this dozen are states with notably extensive tracts of open land.

More than half (23) of the reporting states are those reporting in the negative (or not replying, in four cases) as to a general scarcity of available sites but noting that specific scarcities do exist in particular regions within the state.

Among the 29 states that indicated some scarcities of sites were three (Hawaii, Pennsylvania, and South Carolina) that did not itemize particular regions. Among 32 descriptions supplied by the other 26 states were 14 related to location (in metropolitan areas) and 14 related to physical characteristics (soil and geologic conditions, nine; water table, three; climate, two). Public resistance was mentioned as a factor in four — Idaho, Kansas, New York, and Vermont.

The entire list of regions with a scarcity of landfill sites follows:

Alaska	Parts of southeastern Alaska and areas north of Fairbanks are not suited for sanitary landfills.
Arizona	Winslow area — largely scabland with little cover.
Arkansas	The eastern portion of the state has a high-water-table problem.

California	San Francisco.
Colorado	Within municipalities, immediately adjacent to municipalities where geological and climatological conditions are not suitable.
Delaware	Upper New Castle
Florida	Coastal areas because of high water table
Georgia	Metropolitan Atlanta will be experiencing problems in the future.
Idaho	Soil characteristics, water table, land costs, and public objections.
Iowa	In five counties in NE part of Iowa where bedrock is shallow.
Kansas	Kansas City Region due to public opposition to open dumps.
Maryland	In Baltimore and Washington metropolitan areas.
Michigan	Detroit area. They are becoming scarce due to local objections.
Missouri	St. Louis area.
Nebraska	In a few cases along rivers in flood plains.
New Hampshire	The general nature of the topography is not well suited for landfills.
New Jersey	Corridor NE-SW
New York	Metropolitan New York City and western Long Island (Note: Sites not scarce but public opposition is very great.)
Ohio	Scarce in heavily populated areas and in counties where zoning is being enforced.
Oregon	Because of climatology, acceptable sites are rare in western Oregon but prevalent in eastern Oregon.
Rhode Island	In cities.
Tennessee	Some areas in middle and east Tennessee with shallow bedrock.
Utah	Becoming more difficult to locate along the Wasatch Front in Weber, Davis, Utah, and Salt Lake counties.
Vermont	Public resistance
Virginia	Core city areas with major populations.
Washington	Puget Sound area.

An inquiry that produced unanticipated results concerned the ability of state agencies to acquire land and whether they would be permitted to contract for reclamation of such lands via sanitary landfill. The query was evidently poorly phrased or widely misunderstood, since eight states surprisingly answered that "none" of the state agencies have authority to acquire land and three others were uncertain. Also surprisingly, 14 states mentioned only one or more varieties of local government as having land acquisition abilities. Since the power of eminent domain is a virtually universal attribute of state sovereignty (and purchase is a commonplace means of acquisition), it is likely that a preoccupation with solid waste obscured the query's larger dimensions. While the 25 states cannot be powerless to acquire lands, their abilities to reclaim acquired lands via landfill are presently unknown.

From usable inquiry responses we do have data indicating the land acquisition abilities of the state generally in two cases (Alabama and Georgia), state institutions in two (Arizona and North Dakota), numerous state departments in two (New York and Pennsylvania), and the following specialized agencies:

Bureau of Solid Wastes Management in New Jersey

State Environmental Service in Maryland

Division of Lands in Alaska

Conservation agencies in Iowa and Vermont

Water Development Authority in Ohio

Parks departments in Oklahoma and Utah

Department of Natural Resources in Washington

The probability or certainty is that all of the above would be permitted to contract for land reclamation via sanitary landfill. Interestingly, it appears that in only four states are the primary solid waste management agencies thus far specifically so empowered: Maryland, New Jersey, New York, and Vermont.

Public Opinion Considerations

In appraising the hazards to possible initiation of a rail-haul project, 80 percent (32) of the respondents identified public opinion as a factor to be reckoned with, noting the particular necessity to avoid or overcome adverse reaction by inhabitants and authorities in receiving areas. Among the four broad areas of problems considered, this one drew the most comment, expressed with nearer unanimity than any other.

Queried specifically as to whether public attitudes have been a significant factor in selection of solid-waste disposal sites, only three states (Alabama, Kansas, and Nevada) replied wholly in the negative. Delaware and Mississippi qualified negative replies: the former by noting that the public in the area of proposed landfill sites usually objects, and the latter observing that public attitudes have been a factor in coastal areas.

Cases where definite plans for disposal facilities have been thwarted at the point of site selection by adverse public opinion have been cited by a number of states, including:

Arkansas — Fort Smith and Russellville each have selected several sites, but public attitude has caused them to find still others.

Idaho — A public meeting and protest prevented the relocation of a sanitary landfill; one community has been seeking a site for two years.

Iowa — The Des Moines Metropolitan Solid Waste Agency's endeavor to locate in an adjacent county met such strong opposition that one objector purchased the site at higher cost to keep the agency out.

Missouri — St. Louis County was unsuccessful in locating incinerators at any of its sites. Although the county had the money, they did not build them because of public attitudes.

Nebraska — Some regions have been unable to locate sites because everyone wants it in someone else's area.

New Hampshire — One town had chosen a new site for a sanitary landfill and it was approved. However, a development was about to start in the area and the new residents would not accept the location.

New York — People in Orleans County opposed Rochester's waste being disposed of in their adjoining county. Town of Trenton residents, Oneida County, opposed to wastes from portion of the county being disposed of in their town.

Ohio — Several Ohio counties have been ready to acquire and use sanitary landfill sites but local public opinion has forced the boards of county commissioners to look elsewhere.

Tennessee — City of Knoxville has been in site selection process for over a year with no success; public opinion vital.

Utah — Weber County encountered considerable opposition to sanitary landfill sites so went to incineration. Cedar City is encountering extensive opposition to landfill site selection, both from local citizens and an environmental activist group.

Rail haul projects have already been abandoned due to public pressure in several cases, as follows:

In Colorado, at one time El Paso County refused the concept of solid waste from Denver being transported by rail to a remote site in that county for disposal.

In Maryland, rail haul of wastes to strip mines has received adverse public opinion and the proposed project was not implemented.

In New York, people in the Town of Coeymans, Albany County, opposed rail haul and disposal of wastes from Westchester County.

In Pennsylvania, a Philadelphia rail-haul proposal was stopped by public attitude alone — in fact, it precipitated two legislative hearings which resulted in amendments to the Solid Wastes Management Act.

In Virginia, two rail-haul proposals have been rejected by public opinion.

Such experiences show that raw public opinion, uninformed as to alternatives, will predictably be opposed to local disposal of "other people's" refuse, particularly when it is imported (e.g., by rail-haul) from a considerable distance. Public opinion in the dispatching region will, also predictably, take a favorable position, though somewhat less universally or intensively. While these appraisals came from respondents in the current survey, the significant evaluation is that there is virtually no public antipathy to the rail-haul concept itself. The assessment of anticipated public attitudes toward possible rail-haul generally is that it would be neutral in 24 of 39 reporting states, favorable in 11 and unfavorable in only four. A companion inquiry disclosed that in 25 states new public interest in ecology is considered likely to swing public opinion more in favor of landfill than before.

Since newly organized as well as long-established conservation groups are becoming prominent among present day "environmentalists," respondents were asked to estimate the extent of their interest in modern solid-waste management programs and in possible rail-haul operations. While the apparent interest of such groups in modern solid-waste management is reportedly substantial (33 affirmative), the same is evidently not true of rail-haul (32 negative). Some pertinent comments follow.

Arkansas — We have good response in relation to the conversion of open dumps to sanitary landfills and several groups have encouraged the towns with which they are connected to develop collection systems.

California — These groups, in acknowledging concern for proper waste disposal, have attempted to learn more about the problems and solutions and have somewhat tried to disseminate that information. Recycling efforts have been much praised.

Georgia — These groups tend to support any new concept in an effort to improve existing conditions.

Iowa — The Izaak Walton League urged the Des Moines Metro Solid Waste Agency to pursue rail-haul to abandoned quarries and strip mines.

Kentucky – No support has been indicated toward rail-haul or barge-haul.

Maine – There will be a favorable attitude at this session of the legislature, with support by conservation groups, JCC's, League of Women Voters, garden clubs, etc.

Maryland – Ecology groups want to recycle bottles and cans. That's easy – and, too many of us professionals tend to go along with them and ignore the problem of what to do with industrial wastes. Most cities have ignored this problem by leaving it to private collectors to collect and dispose of these wastes.

Missouri – The Conservation Federation of Missouri realizes the need and will probably support solid-waste legislation in the 1971 session of the legislature.

New Hampshire – Several groups are actively studying the problems involved with solid waste and are looking for solutions. These groups are also doing a fine public education job by bringing this information to the surface.

New York – Many groups have expressed an interest in instituting recycling and reclamation programs in their communities. There are a few instances where separation and collection have been done on a voluntary basis.

Rhode Island – Ecology action organizations are actively supporting a local recycling program.

South Dakota – A wildlife group within the state has endorsed a resolution supporting new state legislation for solid waste control.

Responses to the crucial point – of what needs to be done to induce favorable public attitudes – centered primarily on a need for educational or public relations programs, but did not overlook the desirability of high standards and good practices in handling solid waste responsibilities. Typical of this approach were statements that:

More efforts should be made toward proper operation of existing disposal facilities – **Arkansas.**

First and foremost, demonstrate that a sanitary landfill does not breed flies and rodents, does not emit odors, and is not an open burning dump. Forcing present sites to comply with sanitary landfill requirements will be a strong factor in accomplishing this goal – **Georgia.**

Demonstrate ability to perform reliably and more economically – **Kansas.**

Adhere to good practices in sanitary landfill operations. Use demonstration programs for sanitary landfilling – **Mississippi.**

Very strict enforcement to attain highest operational standards and sound planning for all aspects of a management system – **New Jersey.**

Acceptance of landfills can and will be improved by demonstration of good operation. The public will not be convinced any other way – **Oklahoma.**

Change the public image of solid waste disposal by operating successful landfills – **Tennessee.**

Eliminate or convert all open, burning dumps to sanitary landfills. Upgrade faulty incineration – **Virginia.**

Complexities of solid waste problems and alternative approaches to their solution are stressed in suggestions from some of the larger states, such as:

California – Better public education describing needs, alternative solutions, and citizen responsibilities.

Colorado – Reclamation or land improvement must be emphasized. Economics of recycling or reuse should be presented realistically and updated as new methods are considered and economic evaluations made.

Michigan – The public should be made aware of the waste management problem, its complexities, quantities, and financial implications.

New York – A vigorous public education program needs to be undertaken, with greater participation of the public and their municipal representatives in the planning phases of developing sound solid waste management practices.

Smaller states thinking along similar lines include:

Delaware – First, good communication and secondly, education as to need of abolishing open dumping, what good sanitary landfills are, and what the future may hold for recycling and recovery.

New Hampshire – A great deal more on educating people on the advantages and good points of well run solid-waste management programs is needed. The people just do not know the problem, the reason for the problem, or the solution.

South Dakota – The general public must be made aware that better methods are available which may be feasible with proper organization and planning. The many small rural communities are unable to finance a sanitary landfill independently and should be encouraged to utilize a regional approach to defray disposal costs.

Finally several states call for national educational efforts, Arizona suggesting "more and more national publicity on the problem." Maryland calls for "a strong national program pointing out the problems of solid waste handling," adding:

"Air and water pollution programs finally were adequately funded because of public pressure. The public seems to feel getting rid of nonreturnable containers will solve the problem. But the major problem–what to do with toxic, chemical, pathological, explosive and other potentially dangerous wastes–is being ignored by the public, the media, and, most sadly, by the professionals."

Means of Implementing Rail Haul – Ohio Possibilities

A pertinent approach, though not derived from the survey, is offered here to illustrate how rail-haul might be effectuated within the governmental structure and legal climate of a single state. It is derived from a letter dated January 27, 1969 from Research Attorney James R. Hanson of the Ohio Legislative Service Commission. After noting that "it would appear that the Ohio Revised Code now contains mechanisms by which a cross-country solid-waste disposal project could be carried out," he writes:

"A municipal corporation or county that wants to dispose of compacted solid waste in another county, after obtaining a site in the other county by purchase of land, would need to obtain a license from the board of health of the health district in which the site was located. The Revised Code has required this for any site operated after January 1, 1969. Plans and specifications for the site would need to be submitted to the State Department of Health for approval under regulations of the Public Health Council at least 60 days prior to operation. The local board can charge a fee up to $500 per year, or it can waive the fee in the case of a political subdivision. When the local license has been issued, the local board must certify to the State Director of Health that the site has been inspected and is in satisfactory compliance with the Solid Wastes Disposal Law. The license must be renewed annually. The Director annually surveys the districts licensing such sites to determine whether the law is being complied with–if the local district is disapproved the Director takes over administration.

"The local board may suspend, revoke, or deny a license of a solid-waste disposal site or facility for violation of the law, but in the case of a political subdivision it must first afford a hearing. Appeal from an adverse decision is allowed.

"Since the local board of health administering the Solid Wastes Disposal Law in the health district has no explicit relation to the board of county commissioners of that county, there would be no legal necessity for the originating county or city to make any agreement with the county official in the county of disposal, or any county across which the compacted refuse is to be transported. There is still the possibility, however, that such local officials would find the operation offensive and attempt to stop it by legal or political means. The local board of health might become involved and would be uncooperative in issuing or renewing a license. The problem is thus how to provide assurance for the originating jurisdiction that it may safely invest in expensive compacting equipment and land for disposal sites, and secure transportation equipment by purchase or contracts with the railroads.

"One simple method would be to enact a new section to set up a mechanism whereby the originating county or city would get a plan of disposal approved by the boards of health of the health districts affected and by the State Department of Health–such approval to assure renewal of the license for the period of the plan unless revoked by the State Department of Health because of law violations. This would provide complete local approval of the operation, plus state approval, prevent later disturbance of the disposal program by local political change, yet provide a means of governmental control, assuming that the State Department of Health would intervene only if there were a legitimate health objection."

Powers to Move a Mountain

A recent feasibility study by Black & Veatch for the Metropolitan Sanitary District of Greater Chicago has considered the disposal of solid wastes from a metropolitan area. Their report states "No agency is presently organized and empowered to manage a solid-waste disposal system of the scope envisioned in the Ski Mountain project," and that "A new agency will be required and special legislation will no doubt be needed to authorize it." Pertinent to rail-haul is the report's conclusion that "To function effectively, the management agency will require certain powers, including:

– The power of eminent domain to allow acquisition of property.

– Authority to contract on a long-term basis with municipalities, counties, districts, and other governmental agencies.

– Authority to enter into long-term contracts with private contractors, as may be necessary.

– Authority to pay for capital expenditures through debt financing.

– Authority to levy service charges to pay all or a part of capital and operating expenses."

Questionnaire

The questions asked by the Association to develop information for this chapter are given in the following outline:

I. Establishment and Responsibilities of State Agencies in Relation to Solid Wastes Management

Name of Agency ______ ______

Agency Established by:
State Law (cite) ______
Executive Order of:
  Governor (check) ______
  Other official or
  Board (specify) ______

Date Established: ______

Functions related to Solid Wastes Disposal Handled by Indicated Agency (check):
  Assists in Planning ______
  Reviews Local Plans ______
  Technical Assistance ______
  Develops Standards ______
  Financial Assistance ______
  Promulgates Regulations ______
  Requires Conformance ______
  Operates any aspect ______

II. General Problems Related to Possible Initiation of Rail-Haul Disposal of Solid Wastes

1. If Rail-Haul were to be considered within or involving your state, what problems would you foresee of a
   a. legal nature?
   b. technical nature?
   c. economic nature?
   d. public opinion nature?
2. What greater or lesser intensity would attach to any of the above if the rail-haul were to be operated
   a. within a single county?
   b. from one county to another?
   c. within an established special district
      1. wholly within your state?
      2. from your state into another?
      3. from another state into yours?
   d. on a long-haul basis for disposal at a site distant from point of origin
      1. but all within your state?
      2. from your state into another?
      3. from another state into yours?
      4. from one state through yours into another?

III. Legal Considerations

1. What state laws or regulations (give citations in each case; provide copies if convenient) govern
   a. landfill disposal of solid wastes?
   b. rail freight transport (e.g., solid wastes)?
2. Please check specific state responsibilities relative to control of landfill disposal sites:
Survey available sites ______
Hold hearings on sites ______
Require submission of plans for use of sites ______
Establish standards of landfill operations ______
Check compliance with standards ______
Require inclusion of solid wastes disposal plans in local planning ______
Provide technical assistance to local agencies ______
Provide financial assistance to local agencies ______
Other (specify ______
3. Can two or more counties, and/or jurisdictions in different counties, enter into an agreement for (a) disposal of solid wastes? (b) transport of solid wastes?
4. Do any state or local regulations prohibit importation of solid wastes into or through the jurisdiction? Please cite, describe briefly, and furnish copies if convenient.
5. Are you aware of any litigation as to use of land for solid wastes disposal purposes? Please give citation and gist of any court decisions.

IV. Technical Considerations

1. Has a state plan for solid wastes management been adopted? If not, is one in process? What are its main features?
2. Has a formal training program in solid wastes management been instituted (a) for local officials? (b) for state officials?
3. Has the state made any surveys of potential disposal sites? (If so, please enclose copy of report or of major findings).
4. Have any regionally oriented master plans for solid wastes management been developed? If so, please identify source and scope.
5. Has the state a listing of private firms commercially engaged in disposal of solid wastes? If so, please enclose a copy or cite where available.
6. In what respects, if any, do prevailing state laws require state agencies to deal differently with private entities than public agencies on solid wastes matters?

V. Economic Considerations

1. Is a relatively current survey available covering charges for refuse collection and/or disposal in various localities? If so, please supply a copy if made by your agency; cite source if by others.
2. Have you developed any optimum or estimated unit cost (dollars per ton) figures that would apply to: (1) sanitary landfill disposal (2) rail-haul transportation from central loading point to disposal site or (3) full rail haul disposal including both the above? If so in any case, details will be appreciated.
3. Are suitable landfill disposal sites becoming scarce within the state (a) generally? (b) for particular regions? Specify.
4. What agencies of your state have authority to acquire land of such character and extent as would be susceptible to improvement via sanitary landfill procedures? Would they be permitted to contract for land reclamation via landfill if they so desired?

VI. Public Opinion Considerations

1. Have public attitudes been a significant factor in selection of disposal methods and/or sites? Please supply some specifics.
2. Would you anticipate public attitudes toward possible rail haul disposal to be:

	Favorable	Neutral	Unfavorable
Generally	____	____	____
In Receiving Region	____	____	____
In Dispatching Region	____	____	____

3. Do you have reason to believe newly aroused concern for the ecology may tend to swing public opinion more than heretofore toward support of landfill operations?
4. Have conservation groups and similar citizen organizations evidenced any interest in supporting (a) modern solid wastes management programs? (b) a possible rail-haul disposal system? Please indicate which and to what extent.
5. What needs to be done to induce favorable public attitudes?

CHAPTER 6

PUBLIC HEALTH AND ENVIRONMENTAL CONTROL

The occupational health and sanitation problems encountered in the rail-haul disposal of unprocessed wastes, and of wastes processed by high-pressure compaction and size reduction, are essentially the same as those found in other disposal systems for unprocessed wastes which utilize a. an enclosed transfer station, b. vehicles for long-distance transport, and c. sanitary landfills. The problems associated with the disposal of unprocessed wastes are well known. Therefore, this chapter discusses the environmental implications arising from the introduction of processing in the rail-haul disposal system. Emphasis has been placed on the evaluation of high-pressure compaction as a part of the rail-haul system because this process alters favorably the properties of unprocessed wastes to a greater degree than size reduction.

The principal environmental differences between the rail-haul disposal system of compacted or shredded wastes and the unprocessed wastes are associated primarily with the use of heavy machinery in the transfer station and with the changes in physical properties of the refuse to be transported and landfilled.

The environmental aspects pertaining to the collection and storage of the unprocessed wastes in the transfer station remain the same. However, nuisance aspects during post-transfer station transport and landfilling, such as flying paper and dust, are more severe after size reduction of the wastes, but they are practically eliminated by high-pressure compaction.

The size reduction and the high-pressure compaction processes do not create gaseous or liquid pollutants. However, liquids present in the wastes are partially removed during processing. Dust problems are introduced during size reduction but not during compaction processing. Noise pollution is introduced in both cases by heavy machinery, however, it is more severe during shredding than during compaction.

The implications of high-pressure compaction with respect to 1. transfer stations, 2. rail-transport, and 3. landfilling of solid wastes is summarized briefly in the following paragraphs. The implications arising from size reduction processing have not been presented in detail, as other research projects deal specifically with this subject matter.

TRANSFER-COMPACTION STATION

The pollution control measures which must be implemented in the transfer-compaction station are of the same type as those required in any well-organized refuse collection and storage station and in industrial processing stations utilizing heavy machinery for processing. Specialized and elaborate pollution control measures such as those found in chemical processing plants are not required.

The specific requirements can be assessed by evaluating the main functions carried out in the station. These can be broadly subdivided into three groups:

1. Collection and storage of the unprocessed, loose refuse in storage pits,
2. Compaction of loose refuse, and
3. Storage of the compacted bales.

1. Collection and Storage of Loose Refuse

As noted, the collection and storage of the loose refuse requires the same pollution control measures as recommended for well-run transfer or incinerator stations. In both cases, the material is the same and so are the functions of refuse dumping and storage which might cause dust and odor problems. Likewise, any possibility of infections through biological agents and infestation by insects and rodents is similar to that encountered in other closed collection stations.

Dust problems, and to some degree all other problems mentioned before, could be appreciably reduced if the collected refuse were contained in paper sacks. For example, the escape of odors would be partially prevented by the sacks and infestation by insects and rodents would be minimized. The use of sacks would also reduce spillage.

2. Compaction of Loose Wastes

The environmental control measures which must be considered with respect to the compaction process itself are primarily those dealing with liquid release from wet refuse during compaction and the generation of noise by the compaction equipment. The compaction process produces no air or water pollutants.

During a recent study titled "High-Pressure Compaction and Baling of Solid Wastes"[7] it was found that the amount of leachings extracted from the refuse during compaction is small. However, since even small quantities of leachings can emit very unpleasant odors on standing, and since the leachings contain pollutants, adequate provisions should be made to install below the press a system for gathering and disposal of the liquids released during compaction. Dust is released only during dumping of dry refuse in the charging box; it is not produced during compaction; moreover the charging box is covered.

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[7] City of Chicago Project No. 1-DO1-U1-00170-01, *Development and Testing of Compaction and Baling Equipment for Rail-Haul of Solid Wastes*, 1971.

The main pollutant is the noise generated by the compaction press and auxiliary equipment. Control measures should include proper construction of the building and press and proper installation of the press. A soundproofed console should be provided for the press operator if the pumps are not in soundproof enclosures. Soundproof consoles may also be required in other places, especially if the feeding and operating of the press are not integrated by automatic control and sound communication between employees is required. Adequate emergency warning signals, not depending on sound communication, such as flashing lights, should be utilized. However, a soundproof enclosure of the pumps might provide the easiest solution.

3. Storage of Bales

It appears feasible to store bales for up to a week without encountering offensive deterioration. Indications are that wastes decompose more rapidly when compacted than when they are loose, and that the extent of the potential biological activity which occurs during storage depends on storage conditions. The degradation of food and garden wastes appears to be appreciably enhanced, especially if the bales are stacked and kept in close proximity to each other, thereby preventing the dissipation of the heat generated in the bales. Tests carried out in the compaction program indicate that under favorable storage conditions most pathogenes could be destroyed in the transfer station. They also indicate that the main emissions during storage are likely to be water and carbon dioxide produced by aerobic degradation. However, foul odors from anaerobic decomposition may be emitted, especially if the bales contain raw meat wastes. The effect of storage conditions on pathogene destruction, and the possibilities of accelerating the degradation (composting) of refuse by high-pressure compaction of solid wastes, warrant further investigation and development.

The storage of compacted bales requires a ventilated area, especially if the bales are to be kept for some time in a warm building. High-capacity ventilation equipment is not required, however.

4. General Public Health and Environmental Control of Station

In terms of industrial hygiene, working conditions, and occupational health, the compaction-transfer station must be provided with active ventilation for use as needed. The parts of the press and transfer station in contact with the solid waste materials and, in particular, the leachants must be cleaned regularly.

Other control measures needed in the transfer station, none of which is specifically introduced by the rail-haul system, include traffic and fire control, good housekeeping, and temperature and humidity control.

RAIL TRANSPORT OF COMPACTED BALES

During rail transport, consideration should be given to the fact that the degradation of wastes either continues or, with freshly prepared bales, starts during transport. The rail transportation tests (Chicago-Cleveland-Chicago) made with compacted bales during the Compaction Testing Program indicate that the degradation of organic wastes during transport can be appreciable. Air temperature and humidity in the rail car increased, and the bales became wet and warm. Aerobic degradation apparently took place since foul odors were not detected.

As the degradation of wastes can be affected by factors such as enclosed or ventilated cars, air temperature, and humidity, the choice of rail cars should consider the biological activity occurring in the bales. Although active ventilation devices are not required, provisions should be made to allow for the escape of gaseous products, at least during the movement of the rail car. Prolonged standing of refuse cars in rail stations should be avoided.

SANITARY LANDFILLS

The placement of bales into sanitary landfills requires similar control measures as those used for unprocessed or less compacted refuse. They include proper selection of the site to avoid groundwater pollution and the use of suitable cover material. However, in terms of environmental control, solid-waste bale landfills appear to have advantages as compared to existing landfills.

First, in cases of high winds, there is much less chance for papers to be blown around. Second, solid-waste bales do not burn as easily as uncompacted waste materials. Third, it is likely that smoldering fires in the fill, if they occur, will not be as severe as those in existing landfills because the quantity of oxygen in the compacted wastes is low. Fourth, the baled wastes are likely to contain either few or no pathogenes after storage and transport during which time an appreciable amount of heat is generated.

Provisions for the escape of gases should be no more than that required in normal landfills. Controls of leachants from bales do not need to have the same capacity as those required for landfills of unprocessed waste as bales tend to resist water percolation. Provisions for rain water run-off must, of course, be made following normal landfill experience.

In view of the importance of public health and environmental control in solid-waste disposal, an attempt was made during the study to gather and evaluate as far as possible relevant data and information which could be used in the development of rail-haul as a significantly improved instrument for environmental control. These data are presented in Appendix B. Although emphasis has been placed on developing inputs with respect to rail-haul of compacted wastes, many of the data are applicable to other systems.

APPENDIX A

COMPOSITION AND CONSTITUENTS OF MANUFACTURED AND NATURAL PRODUCTS FOUND IN SOLID WASTES

TABLE 36

COMPOSITION OF RESIDENTIAL WASTES (ESTIMATED UNITED STATES AVERAGE PER YEAR)

Type	Weight-Percentage of Total Wastes
Paper Wastes	60.0%
Food Wastes (bound water and solids)	8.5
Glass and Ceramic Wastes	8.0
Metallic Wastes	8.0
Plants and Grass (bound water and solids)	6.5
Plastic Wastes	3.5
Furniture and Boxes	1.5
Construction Wastes	1.0
Textiles	0.5
Dirt and Vacuum Cleaner Catch	1.1
Rubber Wastes	0.2
Leather Wastes	0.2
Household and Garden Chemicals (solids, liquids)	0.2
Paints, Oils, and Varnishes	0.3
Miscellaneous (liquids, special wastes, micro-organisms, etc.)	0.5
	100.00%

TABLE 37

INDUSTRIAL WASTES

Industry	Composition (Process Wastes)
Paper	Sawdust, dust from rag stock, Lime sludge, black carbon residue, paper rejects
Fruit and Vegetable	Scraps of fruit and vegetables, seeds, cobs, oils, processing chemicals
Meat and Poultry	Flesh, entrails, hair, feathers, fat, bones, blood, grease
Dairy	Butterfat, milk solids, ash, acids, discarded milk and cheese
Glass and ceramics	Broken ceramics, some glass, sludges, dusts, chemicals, abrasives
Metallurgical	Emulsified cleaners, machine oils, oily sludge, borings and trimmings, toxic chemicals
Iron Foundries	Cupola slag, iron dust
Plastics	Scraps from molding and extrusion, rejects, chemicals
Textiles	Textile fibers (plastic and natural), rags, processing chemicals, detergents
Construction (including remodeling and demolition)	Sand, cement, brick, masonry, metal, ceramics, plastics, glass
Chemical	Organic and inorganic chemicals and rejects of synthetic products such as fibers, rubbers, pigments; can contain toxic, explosive and radioactive wastes
Lumber and Furniture	Sawdust, wood chips, abrasives, oily rags, upholstery materials, paints, varnishes, scraps of wood, plastics, and textiles

TABLE 38
PAPER WASTES

Type of Paper	Major Constituent $(C_6H_{10}O_5)_x$*	Other Organic Constituents	Fillers, Binders, and Coatings	Ash**
Newspapers	α – Cellulose	Lignin Hemi-Cellulose Pentosans	Rosin, Clay Alum Casein	3.5%
Brown Kraft Paper	α – Cellulose	Lignin Hemi-Cellulose Pentosans	Gum, Starch Clay, Rosin Alum, Resin	6.5%
Corrugated Boxes	α – Cellulose	Lignin Pentosans β & γ Cellulose Hemi-Cellulose	Clay, Starch Glue TiO_2	7.8%
Books and Magazines	α – Cellulose	β & γ Cellulose Lignin	Clay, Starch Rosin, Casein Satin White TiO_2, $CaCO_3$	28.0%
Writing Papers	α – Cellulose	β & γ Cellulose Hemi-Cellulose Lignin Pentosans	Rosin, Clay Alum, Starch Satin White Resin	
Glassine and Grease Papers	α – Cellulose	Hemi-Cellulose Lignin Pentosans β & γ Cellulose	Glycerine Clay, Starch Wax	6.0%
Tissue Papers	α – Cellulose	Lignin Pentosans	Starch	0.7%
Paper Food Containers	α – Cellulose	Lignin Hemi-Cellulose β & γ Cellulose Pentosans	Rosin, Clay Starch, Alum Wax	7.8%
Paperboards	α – Cellulose	Lignin Pentosans Hemi-Cellulose	Clay, Rosin Wax, Starch Resin	7.5%

*Condensed formula of cellulose fiber. **Average values.

References: Ralph W. Komler, *Varieties of Paper and Paperboard*, Waste Paper Utilization Council.
James P. Casey, *Pulp & Paper*, Vol. I to III, Interscience Publishers, Inc., New York

TABLE 39

GLASSES AND CERAMICS

Chemical Composition – Main Constituents								Applications
Glasses*								
SiO_2	CaO	Al_2O_3	Na_2O	MgO	K_2O	B_2O_3	PbO	
70-74	8-13	1-2	13-16	0.3-3.5	0.3-16	—	—	Containers & bottles[1, 2]
67-92	1-8	0-1	9.5-18	0.15-3	0-7	0-0.4	0-14.8	Tablewares[1, 3]
73.6	5.2	1.0	16.0	3.6	0.6	—	—	Light bulbs[2]
71.6	13.0	1.5	14.0	2.0	—	—	—	Windows[2]
67.2	0.9	—	9.5	—	7.1	—	14.8	Decoratives[2]
54.0	13-17	14-15		5.0	—	10-11	—	Fiber glass[3]
67-97	0.3-13	1-4	4-18	—	0.1-12	1-16	0-15	Others[1, 2, 3]

Ceramics		Applications
Clay**	**Feldspar****	China Pottery Bricks Porcelain Enamels Refractories
$(Mg, Ca, K_2)\,O\,Al_2O_3 : nSiO_2\, nH\,O$	$(Ca, K_2, Na_2)\,O \cdot Al_2O_3 \cdot 6SiO_2$	
Sand	**Others:**	
SiO_2	Various Oxides	

*Composition by weight % **Variable composition

References:
1. B. C. Moody, *Packaging in Glass*, Hutchinson & Co., London, 1963
2. R. N. Shreve, *Chemical Process Industries*, McGraw-Hill Book Co., 1967
3. S. R. Sholes, *Modern Glass Practice*, Industrial Publication Inc., 1952

TABLE 40
METALS AND ALLOYS

Type	Chemical Composition – Major & Minor Constituents	Applications
Iron & Iron Alloys Steels	Major: Fe Minor: Cr, Mn, P, S, Ni, Al, Mo, Si, C	Cans, pipes, wires, tools, razors, nails, structural, appliances, furniture
Aluminum & Aluminum Alloys	Major: Al Minor: Cu, Mg, Mn, Si, Cr, Zn, Pb, Bi	Cans, cooking utensils foil, appliances, furniture, structural
Copper & Copper Alloys	Major: Cu Minor: Zn, Pb, Sn, Al, Fe, Ni, Si	Electrical wires, bronzes & brasses, pipes, housewares, decorations
Nickel & Nickel Alloys	Major: Ni Minor: Fe, Cu, Cr, Mo, Si, C, Mn	Thermal & electrical appliances, linings, coatings, construction, washing machines
Lead & Lead Alloys	Major: Zn Minor: Sb, Sn As	Automobile storage battery, pipes, pigments, solders, coatings
Zinc & Zinc Alloys	Major: Zn Minor: Cu, Al, Pb, Mg, Cd	Galvanic coating, roofing paints
Magnesium & Magnesium Alloys	Major: Mg Minor: Al, Zn, Mn	Structural, galvanic protection, instruments, sporting goods, office equipment
Tin & Tin Alloys	Major: Sn Minor: Pb, Cu, Sb	Coatings, solders, foils, housewares
Mercury	Major: Hg Minor: None	Thermometers, UV lamps
Other Metals & Metal Alloys	Co, Mn, Mo, Ta, Th, Ti, W, Cr, Bi, Ag, Au, Pt	Special applications for instruments, equipment, tools, electrical, photography, jewelry, coatings

References: D. E. Gray, *American Institute of Physics Handbook*, McGraw Hill Book Co., 1963
T. Baumeister, *Standard Handbook for Mechanical Engineers*, McGraw Hill Book Co., 1967

TABLE 41

FOOD

Type	Chemical Composition — Main Constituents						
	Water %	Carbohydrates* %	Proteins %	Fats & Oils %	Mineral Matter Major Constituents	Ash %	Others
Vegetable Wastes							
As purchased	79-95	3-17	2-4	0.2-0.4	Ca, Fe, P	0.7-2	Vitamins
Edible portion	68-95	3-28	1-7	0.1-1.2	Ca, Fe, P	0.6-1.5	Vitamins
Dried (beans)	12.6	59.6	22.5	1.8	Ca, Fe, P	3.5	Vitamins
Skeletons, stalks, stems	Legno-celluloses (see Wood in Table 8)						
Fruit Wastes							
Edible portion	65-95	6-34	0.4-4	0.1-1.6	K, Fe, P, Cu	0.3-1	Vitamins acids
Stems, skeletons, peels	Ligno-celluloses (White of orange peel: Pectocellulose)						
Meat Wastes	50-75	0-5	9-29	3-36	Na, Ca, P, Cl, S	0.2-7.3	Vitamins
Meat (fresh)	50-75	0-5	9-29	3-36	Na, Ca, P, Cl, S	0.2-7.3	Vitamins
Meat (cooked)	48-52		10-25	22-29	Na, Ca, P, Cl	1.3-6.1	Vitamins
Bones			56	4	$Ca_3(PO_4)_2$ $CaCO_3$	40	
Blood	98	Trace	2		NaCl, $NaCO_3$	0.15	
Poultry meat	60-73	0-3	16-22	3-36	Na, Ca, P, Fe	1.0	Vitamins
Skin, tissue, tendon	Collagen (Protein), Glycogen (starch) & animal fats						
Fats	Glyceryl esters of fatty acids (100%)						
Fish Wastes							
Fish (fresh)	65-84	0-4	11-23	0.3-20	Ca, P, Fe	1-1.7	Vitamins
Dairy Wastes							
Milk (fresh)	84-88	5	3-6	3-4	Ca, P, Fe	0.7	Vitamins
Cheeses	35-74	0.3-4	18-80	27-37	Ca, P, Fe	1.2-2.9	Vitamins
Butter	15.5	0.4	0.6	81	Ca, P, Fe	Trace	Vitamins
Other Foods	**Main Constituents:**						
Egg shells	Calcium, Chitin: $C_{15}H_{26}O_{10}N_2$						
Coffee	Cellulose, Fat, Sugars, Proteins						
Cereals	Carbohydrates						
Food Additives	Preservatives & Buffers (organic acids), Sweeteners (saccharine), Thickeners (agar-agar), Oils, Nutrients (vitamins)						

Bacteria & Decomposition Products of Foods

	Water %	Proteins %	Fats & Oils %	Mineral Matter Major Constituents	Ash
Bacteria	80-85	8-15	0.54	P,Na,Ca,S	0.5-3
Bacterial Degradation Products of Foods	Organic acids, Aldehydes, Alcohols, etc.				

Putrefaction Products of:	
Proteins	Alkaloids: Aminovaleric acid (meat), Cadaverine and Putrescine (tissue), Diethylamine (fish)
Fats & Oils	Butyric acid
Dairy Foods	Tyrotoxine (alkaloid) - in stale milk

*Starches, sugars, celluloses.

References

M. B. Jacobs, *Chemical Analysis of Food and Food Products*, New York, 1951
Hackh's *Chemical Dictionary*, 4th Edition, 1968
I. F. Gerard, *Meat Technology*, London, 1951
Blank, *Handbook of Food and Agriculture*, New York, 1955

TABLE 42

GARDEN WASTES

Type	Chemical Composition – Main Constituents Grasses & Plants			
	Water	Celluloses, Lignin, Others	Protein	K, Na, Ca, Mg, Fe, P, S, Cl
Blue Grass, Red Top, Fescue Ryegrass, Bent	69-76%	12-24%	5-9%	2-3%
Roots & Tubers:	75-90%	10-25% solids (Celluloses, Lignin, Minerals)		
Leaves & Flowers:	85-95%	5-15% solids (Celluloses, Lignin, Minerals)		

Type	Wood[2]				
	Water	γ – Cellulose* $(C_6H_{10}O_5)_n$	Lignin* C, H, O	Pentosans* (sugars)	Hemo-Celluloses*
Green hardwood	60%	48%	19.5%	19.0%	10%
Green softwood	60%	50%	28.0%	7.5%	15%
Dry hardwood	25%	As above	As above	As above	As above
Dry softwood	25%	As above	As above	As above	As above

Type	Soil, [3] Sand, Other					
	SiO_2	Al_2O_3	CaO	MgO	K_2O	Na_2O
Mineral Soil**	59%	3.7%	5.1%	3.5%	3.1%	3.7%
Organic Soil:	Varying amounts of plant matter and minerals					
Sand & Gravel:	Main constituent: SiO_2 (Quartz & Silica)					
Other Components of Garden Wastes	Industrial dusts: agricultural chemicals: insecticides, rodenticides, herbicides, fertilizers; scraps of household wastes such as paper, plastics and others.					

*Average, dry weight basis. **Average composition of the earth's crust, weight %

References:
1. National Academy of Science, National Research Council, *Feed Composition*, Washington, D. C., Publication No. 1232 (1964); F. C. Blanck, *Handbook of Food & Agriculture*, Reinhold Publishing Co., New York, 1955.
2. J. A. Kent, *Riegels, Industrial Chemistry*, Reinhold Publishing Co., New York; Mantell, *Engineering Industrial Handbook*, McGraw Hill Book Co., 1958.
3. F. E. Bear, *Chemistry of the Soil*, Reinhold Publishing Co., New York, 1955.

TABLE 43
PLASTICS

Chemical Composition	Main Constituents	Applications
Polyethylene	$[\mathrm{-CH_2-CH_2-}]_n$	Packaging: sheets, bags; bottles, toys, housewares
Polyvinyl Chloride (PVC)	$[\mathrm{-CH(C_2-CHCl-}]_n$	Packaging: bottles, containers; toys, floor tile, pipes & fittings, shoes, upholstery
Polystyrene	$[\mathrm{-CH(C_6H_5)-CH_2-}]_n$	Packaging: foam, sheets; appliances, toys, insulation, shoes, panels, cups, lids
Phenolics	$[\mathrm{-CH_2-C_6H_3(OH)-}]_n$	Appliances, telephones, furniture, laminates
Polypropylene	$[\mathrm{-CH_2-CH(CH_3)-}]_n$	Packaging, toys, carpets, blankets, housewares, pipes, tubing, closures
Polyesters	$[\mathrm{-CO-C_6H_4-COO-CH_2CH_2O-}]_n$	Textiles: Dacron, Kodel, Fortrel, tabletops laminates, fixtures, coatings, artificial leather
Polyurethanes	$[\mathrm{-OR-O-CO-NH-\overset{|}{R}-NH-CO-}]_n$	Elastomers, insulation, cloth linings, packaging
Melamine-Formaldehyde (Amino Resin)	$[\mathrm{-NH-C_3N_3:(NHCH_2-)_2}]_n$	Toys, dinnerware, tabletops, knobs, buttons, bottlecaps, fixtures, plywood
Urea-Formaldehydes (Amino Resin)	$[\mathrm{-CH_2-\overset{|}{N}-CO-NH-}]_n$	
Cellulose Acetate	$[\mathrm{-C_6H_7O_2(OH)(OAc)_2-}]_n$	Women's apparel, draperies, upholstery, photographic film, packaging
Acrylics	$[\mathrm{-CH_2-C(CH_3)(CO-OCH_3)-}]_n$	Sunglasses, plexiglas, textiles, panels, paints
Acrylonitrile-Butadiene Styrene (ABS)	$[\mathrm{CH_2-CH(CN)-CH_2-CH{:}CH-CH_2}$ $\mathrm{CH(C_6H_5)-CH_2-}]_n$	Shoe heels,luggage, appliances, construction, furniture
Epoxies	$\mathrm{CH_2-CH-CH_2[-O-C_6H_4-C-}$ $\mathrm{(CH_3)_2-C_6H_4-O-CH_2-CH(OH)-}$ $\mathrm{CH_2-}]_n$	Flooring, linings, tubing, coatings
Polycarbonates	$[\mathrm{-O-C_6H_4-C-(CH_3)_2\,C_6H_4-O-CO-}]_n$	Packaging: film, sheeting; appliances, insulation
Nylons (Nylon 66)	$[\mathrm{-NH(CH_2)_6NH-CO(CH_2)_4CO-}]_n$	Fabrics, packaging, bottles, watch straps, appliances, nuts
Polyacetals	$[\mathrm{-O-CH-(CH_3)-}]_n$	Toys, packaging, zippers
Polyvinyl Acetate	$[\mathrm{-CH_2-CH(OOCCH_3)-}]_n$	Records, adhesives
Saran	$[\mathrm{-CH_2-CCl_2-CH_2-CHCl-}]_n$	Packaging, upholstery, textiles
Teflon	$[\mathrm{-CF_2-CF_2-}]_n$	Packings, linings, seals, coatings, insulation, gaskets
Kel-F	$[\mathrm{-CF_2-CFCl-}]_n$	
Polyvinyl Alcohol	$[\mathrm{-CH(OH)-CH_2-CH(OH)-CH_2-}]_n$	Water soluble packaging

References: *Modern Plastics*, January 1968.
R.N. Shreve, *Chemical Process Industries*, McGraw Hill Book Co. 1967.

TABLE 44
TEXTILES

Chemical Composition – Main Constituents		Application
Synthetic Fibers*		
Polyamides:		
Nylon 66	$(-HN(CH_2)_6NHOC(CH_2)_4CO-)_n$	Women's hosiery, apparel, other fabrics, protective clothing
Nylon 6	$(-(CH_2)_5CONH-)_n$	
Polyesters:		
Dacron	$HO(C_2H_4O_2C\cdot C_6H_4CO_2)_nC_2H_4OH$	Fabrics, shirts, dresses, blouses, knitwear, stuffing for pillows, sleeping bags, fire hose, V belts, comforters, men's and women's summer suits
Others. Vycron Kodel Fortrel		
Acrylics & Modacrylics:		
Orlon	$(-CH_2CHCN-)_n$	Coats, sweaters, work clothing, carpets, pile fabrics, blankets, nets, winter suits, draperies
Others: Acrilan Creslan Dynel Verel		
Vinyls & Vinylidines:		
Saran	$(-CH_2Cl_2C-)_n$	Seat covers, other upholstery, filter cloth, workmen's clothing, heat-sealing fabrics
Vinyon	$(-CH_2ClCH-)_n$	
Polyurethanes:		
Spandex	$(-ORCO_2NHR^1NHCO-)_n$	Elastics, foundation garments, swim suits
Polyolefins:		
Polypropylene	$(-CH_2CH_3CH-)_n$	Ropes, carpets, laundry nets, blankets, sweaters
Fiberglass:	Borosilicate glasses**	Draperies, curtains, bedspreads, tablecloths
Cellulosic Fibers:		
Viscose Rayon	$(C_6H_9O_4\cdot OH)$	Wearing apparel, draperies, upholstery, blends with wool in carpets and rugs
Cuprammonium Rayon	$(C_6H_{10}O_5)_n$	
Cellulose Acetate	$[C_6H_7O_2CCH_3)_3]_n$	
Natural Fibers		
Vegetable Fibers:		
Cotton		
Cellulose	$(C_6H_9O_4\cdot OH)_n$	Blouses, dresses, shirts, sheets, curtains
Linnen		
Cellulose	$(C_6H_9O_4\cdot OH)_n$	Wearing apparel, household articles
Animal Fibers:		
Wool		
Keratine	~51% C; 20% 0; 19% N; 7% H; 3% S	Wearing apparel, blankets, carpets, rugs
Natural Silk		
Fibroin	$(C_{15}H_{23}N_5O_6)_n$	Wearing apparel; also used with other strong threads as backing

References: R. N. Shreve, *Chemical Process INdustries,* McGraw Hill Book Co., 1967, Chapter 35.
Geoffrey Martin, *Industrial and Manufacturing Chemistry; a Practical Treatise; Part I, Organic.* 7th Edition, Revised by E. I. Cooke, 1952, Technical Press, Ltd., Section XIX.
R. J. Block, *Amino Acid Handbook* Charles C. Thomas, Publisher, 1956.
Kirk-Othmer, *Encyclopedia of Chemical Technology,* Interscience Publisher, 1967, Vol. 9.

*See Plastics. *See Glasses.

TABLE 45
LEATHER (NATURAL & SYNTHETIC)

Chemical Composition – Main Constituents		Applications
Natural Leather		
Hide Substance:		
Collagen (Amino Acids)	$C_{102}H_{149}N_{31}O_{38}$	Shoes, belting, gloves, bags, upholstery, apparel
Tannings:		
Vegetable	Complex mixtures of glucosides of various polyphenols	Heavy leather component
Synthetic	Condensation products of sulfonated phenols and formaldehyde	Auxiliary and complementary agents
Chrome	Basic chromic sulfate $Cr(OH)SO_4$ or sodium dichromate $Na_2Cr_2O_7$	Light leather component
Fats		
Glycerides of:		
Stearin	$C_3H_5(O{\cdot}C_{17}H_{35}CO)_3$	
Palmitin	$C_3H_5(O{\cdot}C_{15}H_{31}CO)_3$	
Olein	$C_3H_5(O{\cdot}C_{17}H_{33}CO)_3$	
Fillers:	$MgSO_4$; Cellulose	
Dyes & Pigments:	See Paints	
Synthetic Leathers*		
Neolite	Styrene-acrolonitrile butadiene	Shoe soles and heels, luggage
Corfam	Polyester, urethane	Shoe-uppers, belting
Patent Leather	Vinyl polymers, urethane	Shoes, handbags, belts
Others	PVC; nylon, ionomer, spunbonded polyester; polyurethane, viscose	Shoes, shoe linings, bags, leatherlike fabrics, apparel

*See Plastics.

References. Geoffrey Martin, *Industrial and Manufacturing Chemistry; a Practical Treatise; Part I, Organic.* 7th Edition, Revised by E. I. Cooke, 1952, Technical Press, Ltd., Section XIX.
R. N. Shreve, *Chemical Process INdustries,* McGraw Hill Book Co., 1967, Chapter 25.

TABLE 46

RUBBERS (SYNTHETIC & NATURAL)

Chemical Composition – Main Constituents		**Applications**
Synthetic Rubbers*		
Polybutadiene	$-CH_2CH:CH(CH_2)_2CH:CHCH_2$	Tires, waterproofing of fabrics, shoe soles and heels, rubber boots, swim suits, foundation garments, linings, building, putties, cements, flooring, pillows, mattresses, upholstery, tubes, pipes, hose, insulation, packings, rainwear, building panels, tennis and golf balls, gaskets, sealants, combs, belting, etc.
Polyisoprene	$-CH_2CH_3C:CHCH_2-$	
Neoprene	$-CH_2CC1:CHCH_2-$	
Styrene-Butadiene	$-CH_2CH:CH(CH_2)_2CHC_6H_5-$	
Nitrile	$-CH\ CH:CH(CH_2)_2CHCN-$	
Polysulfide	$-CH_2CH_2S_4-$	
Butyl	$-C(CH_3)_2(CH_2)_2CH_3C:CHCH_2-$	
Polyurethane	-OROCONHRNHCO-	
Silicon	$-OSi(R)_2OSi(R)_2-$	
Others:	Acrylic, Plastisized polyvinylchloride, etc.	
Rubber Fillers**	Sulphur, Clay, $CaCO_3$, Coal, Silica	Hard Rubber contains about 25-40% of Sulphur
Natural Rubber		
Rubber Hydrocarbon:	$-CH_2CR:CHCH_2-$) 93.3%	See Synthetic Rubbers
Others:	Fatty acids, Sterols)	
	Proteins, Esters,)	
	Inorganic salts,) 6.7%	
	Moisture)	
	100.0%	

*See Plastics. **Synthetic and natural rubbers contain about 50 parts of filler for 100 parts of rubber.

References: R. N. Shreve, *Chemical Process Industries*, McGraw Hill Book Co., 1967
J. A. Kent, *Industrial Chemistry*, Reinhold Publishing Corp., New York, 1962

TABLE 47
CHEMICAL COMPOSITION – MAIN CONSTITUENTS

Type	Chemical Composition – Main Constituents
Soils:	
Mineral Soil	SiO_2, Al_2O_3, CaO, Fe_2O_3, etc.
Organic Soil	Organic plant matter and mineral soil (See Garden Wastes)
Industrial Dusts:	
Fly Ash, Cement Dust, Metallurgical Dusts, Foundry Dusts, Oil Smoke	SiO_2, Al_2O_3, Fe_2O_3, Carbon, Sulphur, Oil, Metal Powders
Fibers: (from carpets and textiles)	Wool, Cellulosics, Acrylics, Polyesters, etc. (See Textiles)
Hair: [1]	Keratine Substance: Carbon 51% Oxygen 21% Nitrogen 16% Hydrogen 6% Sulphur 6%
Food Scraps:	Fats, Proteins, Carbohydrates (See Food Wastes)
Metal Scraps (pins, needles, etc.)	Iron, Steel, Aluminum (See Metals & Alloys)
Others:	Powdered household chemicals, Paper scraps, Glass fragments, Bacteria, etc.

[1] R. J. Block, *Amino Acid Handbook*, 1956

TABLE 48

VARNISHES AND LACQUERS

Chemical Composition – Main Constituents				
Oils	**Solvents & Thinners**	**Resins**	**Pigments & Extenders**	**Others**
Mixtures of Esters of Glycerin ($C_3H_5(CH)_3$) and various fatty acids such as: **Saturated Acids** Palmitic Stearic Arachidic **Unsaturated Acids** Oleic Linoleic Linolenic **Hydroxyl Acids**	Mineral Spirits Turpentine Dipentene Naphthas Xylol Xylenol Toluol Benzol Esters Ketones Alcohols Ethers	Shellac Resin Latex Phenol-Aldehyde Alkyds Acrylates Vinyl Resins Chlorinated Rubber & Diphenyl Copolymer Latex Cellulose Derivatives Mannitol Esters Pentaeerythritol Esters Limed Rosin Ester Gum Copal Dammar Epoxies	Lead compounds: $PbCO_3$, $PbSO_4$, PbO Calcium compounds; $CaSO_4$, $CaCO_3$, CaO Barium compounds: $BaSO_4$, $BaCl_2$, BaS Zinc compunds: ZnO, ZnS Titanium Dioxide: TiO_2 Oxides of: Co, Cr, Fe, Cu Silica, Talc, Metallic Powders Carbon: Amorphous Crystalline Phthalocyanides Ferrocyanides Toluidines Chloro Aniline & Analine Derivatives	Dryers: Naphthenates of: Co, Mn, Pb, Zn Resinates Octoates Linoleates Tallates Thickener: Casein (Protein) Plasticizers: Phthalates Phosphates Antiskinnings: Polyhydroxy Phenols Alkalies Chlorinated Phenols Copolymers

Reference: R. N. Shreve, *Chemical Process Industries*, McGraw-Hill Book Co., 1967, Chapter 24

TABLE 49

INSECTICIDES

Chemical Composition – Main Constituent		Function of Components
Halogenated Hydrocarbons		Toxicans
DDT	$C_{14}H_9Cl_5$	
Methoxychlor	$C_{16}H_{15}O_2Cl_3$	
Chlordane	$C_{10}H_6Cl_8$	
Lindane	$C_6H_6Cl_6$	
Dieldrin	$C_{11}H_8Cl_6$	
Strobane	Unknown	
Perthane	$C_{18}H_{20}Cl_2$	
Sulphur Hydrocarbons		
Malathon, etc.	$C_{10}H_{19}O_6PS_2$	
Saturated, Unsaturated & Aromatic Hydrocarbons	Kerosene, etc	Solvents
Methylene Chloride	CH_2Cl_2	
Dichlorodifluoromethane	CF_2Cl_2	Propellants in aerosols
Trichlorofluoromethane	$CFCl_3$	
Allethrin	$C_{17}H_{26}O_3$	Knockdown agents
Pyrethrum	$R^1 \cdot C_{15}H_{17}O_3 \cdot R$	
Lethane	$C_8H_{17}O_2CNS$	
Thanite	$C_{11}H_{17}O_2CNS$	
Sulfoxide	$C_{25}H_{18}OS$	Synergists
Piperonyl Butoxide	$C_{19}H_{30}O_5$	
MGK 264	$C_{17}H_{27}O_2N$	
Arsenites Fluorides Mercury Compounds Phosphides, Cyanides, Sulphur Compounds		Inorganic toxicans

Reference: Merzka & Pickthall, *Pressurized Packaging, Aerosols*, Academic Press, Inc., New York, 1958

TABLE 50
COSMETICS

Chemical Composition – Main Constituents		Application
Active Ingredients		
Halogenated Compounds		
Aluminum Chlorhydrol	$Al_2(OH)_5 \cdot Cl \cdot 2H_2O$	Deodorants
Aluminum Chloride	$AlCl_3$	Deodorants
Hexachlorophene	$C_{13}Cl_6H_6O_2$	Deodorants
Methylene Chloride	CH_2Cl_2	Hair sprays &
Polyvinylpyrrolidone	$(-CH \cdot C_4H_6ON \cdot CH_2-)_x$	Shaving creams
Sulphur Compounds		
Zinc Sulphocarbolate	$Zn(O_3SC_6H_4OH)_2 \cdot 8H_2O$	Shaving lotions
Aluminum Sulphocarbolate	$Al(O_3SC_6H_4OH)_3 \cdot nH_2O$	Deodorants
Triethanolamine Lauric Sulphate	$C_{12}H_{25}SO_4C_6H_{14}O_3N$	Shampoos, shaving creams
Sodium Lauryl Sulphate	$C_{12}H_{25}SO_4Na$	Shampoos
Oils		
Vegetable	Glycerides	Sun lotion
Mineral	Paraffins & Olefins	Brillantine, lipstick
Silicone	$-R_2SiO-$	Hand cream
Essential	Aromatic Aldehydes	Perfumes, lotions, etc.
Miscellaneous		
Stearic Acid	$C_{17}H_{35}COOH$	Vanishing cream
Stearates	$C_{17}H_{35}COOM$	Cold & Vanishing cream
Glycerol	$(CH_2OH)_2CHOH$	Creams, lotions
Isopropyl Myristate	$C_{13}H_{27}CO_2CH(CH_3)_2$	Creams, lotions
Triethanolamine	$(C_2H_4OH)_3N$	Creams, lotions
Triethanolamine Laurate	$C_{11}H_{23}CO_2C_6H_4O_2N$	Shampoos
Sulphides	Na, Ba-sulphides	Depillatories
Pigments	ZnO, TiO, Stearates	Face powders
Talc	$3MgO \cdot 4SiO_2 \cdot H_2O$	Talcum powder
Alcohols	C_2H_5OH, etc.	Perfumes, lotions
Propellants		
Halogenated Compounds		
Dichlorodifluoromethane	CCl_2F_2	Propellant agents in sprays
Dichlorotetrafluoroethane	$CCl_2F \cdot CF_3$	
Trichlorofluoromethane	CCl_3F	

Reference: The Merck Index, Merck & Co., Inc., 8th Ed., 1968

TABLE 51
CONSTRUCTION WASTES

Chemical Composition – Main Constituents		Applications
Structural Clay Products	Various Clays [1]	Building brick, face brick, tiles, terra-cotta
Gypsum	$CaSO_4 \cdot 2H_2O$	Plasters, wallboard, roof & partition tiles
Woods	Cellulose[2]	Plywood, frames, fiber & particle boards, panels, flooring
Papers	Cellulose[2]	Construction paper, paperboard, core material, wallpaper
Plastics	Acrylics, Phenolics PVC, Alkyds, Polyesters, Polycarbonates, Polyurethanes, Epoxies, Polypropylene, Polystyrene Aminos[3]	Decorative & structural panels, tiles, windows, adhesives, laminates, decorative fixtures, putty, insulation, pipes, fittings, seating
Metals	Al, Aluminum alloys, Fe, Steel, Brass[4]	Frames, fixtures, pipes,
Glasses	Glasses[5]	Windows, plates, foamed glass, fiberglass reinforcements & insulation
Refractories	SiO_2, Al_2O_3 rich clay	Fire brick, linings, mortars
Porcelain & Enamels	Ceramics[1]	Plumbing, fixtures, insulation tiles
Concrete	$CaO \cdot SiO_2$, $CaO \cdot Al_2O_3$, $CaO \cdot Al_2O_3 \cdot Fe_2O_0$	Foundations, walls, floor & roof slabs, sinks, steps
Lime Cement	CaO	Plaster, mortar, stucco
Sand & Gravel	SiO_2, Mica, Feldspar[1]	Aggregates: cements, plaster
Lime, Sand, Soapstone	$CaCO_3$, SiO_2, Talc	Steps, floor & roof tiles, tubs
Mortars	Clays, Refractories	Fillers, binders
Vermiculite	Oxides of Si, Mg, Al, Fe, K, Ca	Aggregate in plaster, acoustical plastic, concrete, fill insulation
Others	Asphalt, Asbestos, Paints, VArnishes & Laquers[6], Fly Ash Perlite, Cork, Oils, Gums	Fillers, insulation, waterproofing, hardeners, sealers, binders

[1] See Ceramics [2] See Wood & Paper [3] See Plastics [4] See Metals & Alloys
[5] See Glasses [6] See Paints

References: Mantell, *Engineering Materials Handbook*, McGraw-Hill Book Co., 1959
R. N. Shreve, *Chemical Process Industries*, McGraw-Hill Book Co., 1967

TABLE 52
OVERSIZED WASTES

Type	Chemical Composition – Main Constituents	Applications
Appliances		
Metals & Alloys	Steel, Al, Fe, Cu[1]	Refrigerators, stoves, dryers, washing machines, TV's, dishwashers, humidifiers, air conditioners, space heaters, warm water heaters, boilers, lawn mowers, sewing machines
Plastics	Polystyrene, Phenolics[2]	
Others	Wood[3], Glass[4], Paints[5]	
Furniture, Fixtures		
Wood	Cellulose[3]	Tables, chairs, cabinets, bookcases, beds, sofas, desks, lighting, bath & kitchen fixtures
Plastics	Urea & Melamine	
Metals & Alloys	Al, Steel, Cu, Ni[1]	Filing cabinets, bed springs
Upholstery	Textiles[6], Rubbers[7] Foams[2], Leather[8]	Sofas, chairs, beds
Soft Furnishings	Textiles[6] Rubbers[7] Plastics[2]	Carpets, bedding, pillows, drapes
Plumbing & Bath	Pb, Cu, Al-Alloys[1] Acrylic, Polystyrene[2]	
Recreational	Metals & Alloys[1]	Bicycles, play equipment
	PVC, ABS, Polyester[2]	Swimming pools, play equipment, toys
Others	Lead, Aluminum[1]	Batteries, Christmas trees
	Plastics[2]	Room dividers, flooring
	Rubber[7]	Tires, garden hose
	Wood & Paper[3]	Crates, brush, stumps, doors, cardboard, fencing, Christmas trees

[1] See Metals & Alloys. [2] See Plastics. [3] See Wood & Paper. [4] See Glass & Ceramics. [5] See Paints, Varnishes & Lacquers. [6] See Textiles. [7] See Rubbers. [8] See Leathers.

APPENDIX B

BACKGROUND INFORMATION: CONTROL MEASURES FOR PUBLIC HEALTH AND ENVIRONMENTAL CONTROL

The information given in this appendix is a detailed account of factors and control measures which should be considered in all solid-waste disposal systems. Included is information on noise, dusts, toxic and foul smelling bacterial degradation products from loose and compacted waste, liquid and gaseous release during and after compaction, and data on disease associated with solid wastes.

Noise in Transfer-Compaction Station

Two major sources of noise must be considered in the design and operation of a transfer-compaction station. One is associated with the operation of transport vehicles delivering the wastes, and the other with the operation of machinery (compaction press and auxiliary equipment) utilized in the compaction process.

The generation of noise by delivery trucks is well known. It is encountered in all transfer stations and as such does not represent a new noise element. However, since it is not the only major source of noise in a compaction station, it should be re-evaluated with respect to its contribution to the overall noise level. The number and frequency of waste deliveries will affect the necessary measures to be taken in a given station. Infrequent deliveries of short duration are unlikely to pose problems. However, a continuous flow of noisy vehicles might require improvement in acoustics of the station or even a separation of the collecting section from the processing section of the building.

The other major source of noise in the station is the compaction press itself, although auxiliary processing equipment such as cranes will also contribute to the overall noise level. The noise generated by compaction presses is appreciable and care should be taken during design to reduce the level as far as possible. Even so, all machinery operations tend to be noisy and as a result interfere with communications. Excessive noise could introduce safety hazards since it interferes with warning signals propagated by sound. Therefore, other types of safety warning signals would have to be installed, such as flashing lights, and in cases in which sound communication between employees is required, provisions will have to be made to soundproof specific areas. The latter requirement applies specifically to any employee operating equipment which has to be integrated with other operations if the operations are not carried out by automatic control. Special attention should be given to the noise generated from shredding equipment, if it is used as a pre-processing method. As a rule, shredders, such as hammermills, are much noisier than compaction presses.

In addition to the effect of noise on communications and to its related safety hazards, consideration should be given to its effect on the health and efficiency of the working personnel. The exact nature of the physiological and psychological effects of noise, outside extremely high intensity exposures, is not fully known. However, the efficiency of human effort, whether mental or manual, is known to depend very largely on the prevention of fatigue. Authorities on industrial economics claim that the greatest waste in industrial operations is caused today by nervous fatigue produced by excessive and continuous noise. Nervous fatigue induced by incessant operation of the noisy equipment could affect both efficiency and awareness and therefore safety of the working personnel. Some gain in efficiency has been reported for workers using earplugs; however, the beneficial effect of earplugs appears to be limited.[8]

1. Noise and Vibration Control

In view of the negative effects which can be produced by the noise generated in any industrial station which employs heavy machinery, preference should be given to the use of construction materials with sound-insulating properties. Practical solutions include stiff and heavy brick or masonry walls or equivalent insulation, and good foundations. In addition, since noise arises from nonperiodic sound waves which are transmitted through the air from vibrating sources, special attention also should be given to localized vibration control. The most general principle of localized vibration control is that vibrations should be damped out as near as possible to their source. Concerning the compaction press, this means that it shall be of correct design, properly balanced, and with adequate foundations.

When the compaction station is in operation, noise surveys should be made to define potentially annoying sounds and their origin. It is recommended that the sound level in the station should not exceed

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[8] **Harris, C.M. (Ed.), *Handbook of Noise Control*, McGraw Hill Book Co., Inc., New York (1957).**

70 decibels or as governed by local noise control ordinances. Typical sound levels originating from different sources are given in Table 53.

TABLE 53
TYPICAL SOUND LEVELS

	Decibels	
Deafening		
	120	Threshold of feeling: thunder, artillery
	110	Nearby riveter Elevated train
	100	Boiler factory Loud street noise
Very Loud		
	90	Noisy factory Truck unmuffled
	80	Police whistle Noisy office
Loud		
	70	Average street noise Average radio
	60	Average factory Noisy home
Moderate		
	50	Average office Average conversation
	40	Quiet radio Quiet home or private office
Faint		
	30	Average auditorium Quiet conversation
	20	Rustle of leaves Whisper
	10	Soundproof room Threshold of audibility

Noise surveys in the station should include measurements of the frequency, duration, and intensity of the noise, and the physical characteristics of the noise source. Remedial action should be taken to eliminate sources of excessive noise whenever possible. Personnel operating continuously a noisy piece of equipment, such as a nonmodified press, should be provided with a soundproof console. It is also advisable that employees exposed to the noise continuously should be tested for their hearing in order that preventive measures can be taken to eliminate possible hearing losses of sensitive individuals.

2. *Audiometric Testing of Employee Hearing*

In order to determine whether the noise generated in the compaction station affects the hearing of the employees, periodic audiometric tests should be made under the direction of a qualified person. A pre-employment test should be given and a history taken in which prior ear disease, exposure to noise, or any deafness in the family is noted. Testing should be repeated every 9 to 36 months. Audiometric testing criteria[9] and Hearing Conservation Data Cards[10] have been developed. A method for classifying the hearing of employees has been worked out[11] and some modifications[12,13] have been recommended. The modifications for classification suggest referencing audiometric measurements to absolute hearing thresholds rather than to a central value. The advantages of the introduction of audiometric zero reference levels are: a. negative thresholds are eliminated, b. the horizontal straight-line reference profile of the 1964 WHO ISO audiometric standards is maintained, c. the American Academy of Ophthalmology and Otolaryngology rule of estimation of percentage of impairment of hearing is more easily applied to data referenced to these new levels, and d. the full range of normal hearing is included in the audiometric scale. The grading systems of the modified hearing evaluation chart is shown in Table 54.

The Early Loss Index (ELI), which is a measure of hearing decrements in the Hertz range, can be used to advantage to predict future hearing losses so that preventive measures may be taken. A system of grading ELI is shown in Table 55.

Recently, a new method for predicting susceptibility to noise-induced hearing loss has been developed.[14] This method utilizes tests of Temporary

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[9] American Industrial Hygiene Association, *Industrial Noise Manual*, Second Edition, American Industrial Hygiene Association, Detroit (1966).

[10] Subcommittee on Noise, Committee on Conservation of Hearing, American Academy of Ophthalmology and Otolaryngology, *Hearing Conservation Data Card*, Revised, June 1968.

[11] Guide *For Conservation of Hearing in Noise*, Prepared by Subcommittee on Noise of the Committee on Conservation of Hearing and Research Center Subcommittee on Noise. A supplement to the *Transactions of the American Academy of Ophthalmology and Otolaryngology*, Los Angeles 1964.

[12] Hermann, E.R., "Environmental Noise, Hearing Acuity and Acceptance Criteria," presented at the Midwest Acoustics Conference, April, 1968.

[13] Hermann, E.R., and Holymann, E.R., "Absolute Thresholds of Human Hearing" Reprinted from *American Industrial Hygiene Association Journal*, 28: 13-20, (January-February, 1967).

[14] Smith, Paul F., Jr., "A Test for Susceptibility to Noise-Induced Hearing Loss." Presented at the American Industrial Hygiene Conference, St. Louis, Missouri; May 1968, submitted to the American Industrial Hygiene Association Journal.

TABLE 54

MODIFICATION OF HEARING EVALUATION CHART BASED ON KNOWLEDGE OF ABSOLUTE THRESHOLDS OF HUMAN HEARING

Classes of Hearing						
(db)	Class	Degree of Handicap	Mean Hearing Level (1964 ISO plus 24 db) 500, 1,000 and 2,000 Hertz in the Better Ear*		Hearing Characteristics	
0						Absolute Thresholds of Hearing (after Hermann & Holzman)
25	A	Normal			Excellent and very good hearing range	Audiometer Zero (1964 ISO)
35		Not Significant	At least	Less than 50	No significant difficulty with faint speech	Audiometer Zero (1951 ASA)
50	B	Slight	50	65	Difficulty only with faint speech	"Low Fence"
65	C	Mild	65	80	Frequent difficulty with Normal speech	
80	D	Marked	80	95	Frequent difficulty with loud speech	
95	E	Severe	95	115	Can understand only shouted or amplified speech	Educational Deafness
115	F	Extreme	115		Usually cannot understand even amplified speech	"High Fence"
135						Usual Limit of Audiometer output

*If the average of the poorer ear is 25 db or more greater than that for the better ear, add 5 db to the average for the better ear.

TABLE 55

EARLY LOSS INDEX, 4,000 HERTZ AUDIOMETRY

Age	Age–Specific Presbycusis, db Men	Grade	ELI Scale Exceeds ASPV by:	Remarks
25	0	A	<8 db	Normal-excellent
30	3	B	8-14	Normal-good
35	7			
40	11	C	15-22	Normal-within
45	15			
50	20	D	23-29	Suspect noise-induced loss
55	26			
60	32	E	30 or more	Strong indication of noise induced loss
65	38			

Thresholds Shifts (TTS) at 3,000 and 4,000 Hertz after exposure at 2,000 Hertz. Plots of the temporary threshold shift against pre-exposure hearing thresholds of 30 volunteers are shown in Figure 28. The lower curve represents the line of regression and the upper curve one standard deviation plus the regression line. It has been postulated that persons giving TTS values above the one standard deviation line might be considered high risk candidates for Noise Induced Permanent Threshold Shifts (NIPTS).

Dusts in Transfer–Compaction Station

Dusts are released from solid wastes primarily during the dumping of loose refuse in the storage pit and to some degree during loading of [illegible] press charging box. Dust problems could be practically eliminated if the wastes would be contained in paper or plastic sacks. However, severe dust problems could be introduced by the shredding of wastes and the dumping of shredded wastes. Compaction itself does not introduce dust problems, nor does the handling of compacted bales.

There are several types of dusts which can be released from loose solid wastes. They can be broadly classified as:

1. Inert or "Nuisance" particulates,
2. Inert or "Nuisance" particulates contaminated with either traces of toxic chemicals or laden with bacteria, and
3. Toxic dusts.

The main components of dusts from household wastes are usually inert or nuisance particulates of low order of activity. In concentrations ordinarily encountered, these dusts do not cause physiological impairment. A threshold limit of 50 millions of particles per cubic foot (mppcuft) has been recommended for substances in this category for which no specific data are available.[15] The limit applies to a normal 8-hour work day; brief exposures

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[15] Threshold Limit Values 1967, Conference of Governmental Industrial Hygienists, Chicago, Illinois, May 1967.

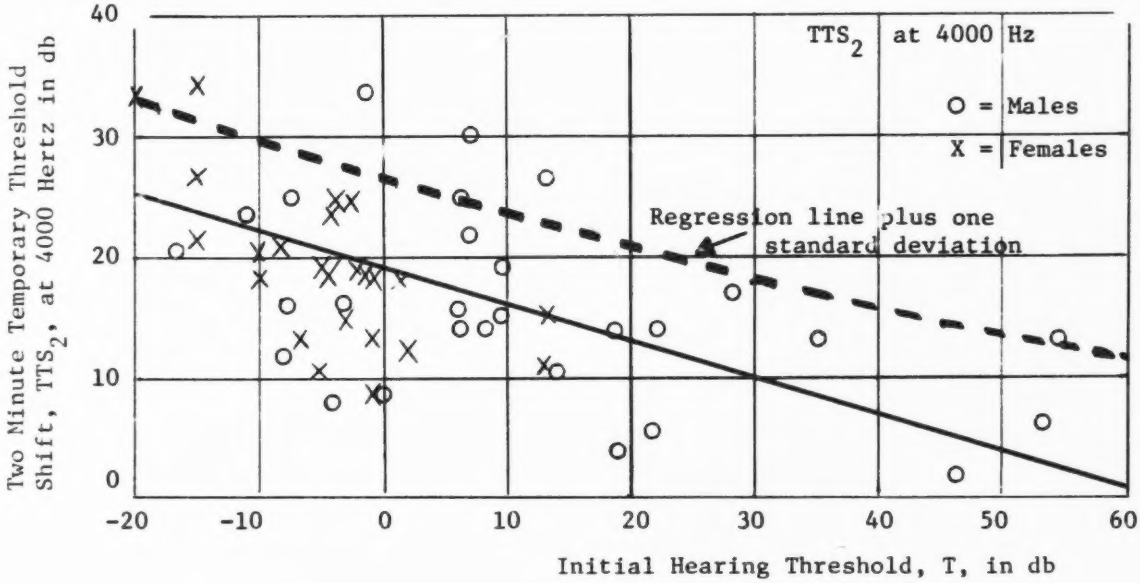

FIGURE 28

PLOT OF REGRESSION LINE OF TWO MINUTE TEMPORARY THRESHOLD SHIFT at higher concentrations can be tolerated. Clean air, such as outdoor air in rain, contains about 0.3 mmpcuft dust particles in comparison to the recommended limit of 50 mmpcuft. On the other hand, the concentration of dust in coal mines has been estimated to be 112 mmpcuft.[15]

So far, only a limited number of nuisance particulates associated with solid wastes have been rigorously tested. Those reported in the literature are listed in Table 56. They include both soluble and insoluble, organic and inorganic, constituents. Insoluble components, such as cellulose, cement, iron, steel, and titanium dioxide, tend to accumulate in the respiratory passages. The accumulation of soluble dusts, such as starch and calcium carbonate, is only temporary.

Most nuisance dusts contain predominantly mineral particles. This is likely to be true for solid waste dusts also; however, it is conceivable that refuse dusts could be mainly organic in nature. Large quantities of the organic dust, especially cellulose, could be produced during the handling of dry, shredded wastes.

As mentioned before, the bulk of dusts generated in transfer stations belong to the nuisance category. However, it should also be recognized that ordinary dust particles can be contaminated either with traces of chemical toxic impurities or that the dusts could be laden with disease-carrying bacteria. The threshold limit allowable for contaminated nuisance dust is obviously less than for non-contaminated dusts.

Toxic impurities attached to dust particles could be either solid or liquid. It should be emphasized that as a rule households discard only very small quantities of toxic dusts and liquids. Traces of toxic powders and liquids could be introduced through a variety of household chemicals, especially those used in the control of insects, germs, rodents, and garden vegetation, and through chemicals used for housecleaning purposes. Paints can contain, occasionally, toxic pigments and solvents; vacuum cleaner catches may incorporate traces of toxic industrial dust. However, toxic substances produced during bacterial degradation of food wastes, especially from meat and fish, are likely to be present in traces in most waste loads. Some toxic categories and components of wastes are listed in Table 57.

Toxic substances produced during the decomposition of foods and pathogenic organisms which have been associated with wastes are discussed

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[15] Hackh's *Chemical Dictionary*, McGraw-Hill Book Co., Fourth edition, 1969.

TABLE 56

"INERT" OR NUISANCE PARTICULATES

Chemical Composition	Components of:*
Organic	
Cellulose	Paper, wood, vegetable & fruit wastes
Starch	Food wastes
Sucrose	Food wastes
Inorganic	
Nuisance dust (no free silica)	Soil, industrial dusts
Alundum (Al_2O_3)	Industrial dust
Iron & Steel Dust	Industrial dusts
Calcium Carbonate	Paints, construction wastes
Portland Cement	Construction wastes & dust
Gypsum	Construction wastes & dust
Limestone	Cement, fertilizer
Magnesite	Refractories
Plaster of Paris	Construction wastes
Tin Oxide	Pigment
Titanium Dioxide	Pigment in paper, paints, rubber, ceramics, shoe polish

*See Tables 38-52

TABLE 57

SOME TOXIC DUSTS, LIQUIDS, AND OTHER COMPONENTS IN HOUSEHOLD WASTES (TRACES)

Chemical Composition	Origin in Waste
Organic: Chlorinated, Sulphur & Phosphorous compounds, etc.	Insecticides, germicides, weed Killers, rodent killers
Inorganic: Arsenites, Cyanides, Mercury compounds, etc.	
Lead, Copper, Chromium, Zinc and soluble Barium compounds	Pigments in paints
Mercury (liquid metal of high vapor pressure)	Thermometers, UV lamps
Sulphur compounds	Industrial dusts, chemicals
Turpentine, Cresol, Phenol	Liquid solvents in paints and household chemicals
Acids, Alkalies	Household chemicals
Alkaloids and Clucosides (Ptomaines[1])	Decomposed food (solids and liquids)
Disease - carrying microorganisms[2]	Contaminated food, feces, textiles, solid objects and dusts

Notes: [1] See Tables 58, 59.
[2] See Tables 62,63.

in the following sections. As a rule, dusts can harbor large numbers–in the millions–of microorganisms. However, only disease-carrying organisms are of concern.

With respect to the liquid components mentioned in Table 57, it should be recognized that these substances can emit vapors in addition to being able to attach themselves to dust particles. They can, therefore, contribute to air pollution in the absence of dusts. However, with the exception of the substances produced during the decomposition of foods, and mercury, none appear to warrant special attention. Exposure to air containing 0.00012 percent mercury has been found to cause poisoning.[16]

Since mercury tends to remain in small crevices, it might accumulate in spite of housecleaning. Simple tests are available for detecting mercury vapors, and so are noncorrosive powdered chemicals, which can be sprayed onto the contaminated area to convert the metal into compounds of low vapor pressure which are easily accessible to ordinary cleaning methods.

The main source of air pollution in transfer/compaction stations, other than dust, therefore, is the formation of liquid and gaseous decomposition products from decaying organic matter.

Toxic Substances and Odor Degradation of Food Wastes

As previously mentioned, decomposed wastes can contain toxic substances. Toxic solid, liquid, and gaseous products may be formed as a result of progressive chemical decomposition of organic matter, especially from proteins of animal origin. During the putrefactive degradation by anaerobic bacteria, the proteins are decomposed to toxic amino compounds (alkaloids) which often emit foul-smelling odors. These putrefactive alkaloids, and some toxic glucosides, belong to the class of Ptomaines. A number of Ptomaines, and the waste from which they originate, are listed in Table 58.

Many of the liquid and solid putrefactive compounds give off vapors of foul odors. These, together with other decomposition compounds, are presented in Table 59.

The concentration of vapors and gases emitted

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[16] Hackh's *Chemical Dictionary*, Fourth Edition, McGraw-Hill Book Co., 1969.

TABLE 58

PTOMAINES:*[1] TOXIC, PUTREFACTIVE ALKALOIDS PRODUCED BY BACTERIAL DEGREDATION OF FOOD WASTES

Toxic Amino Components	Source
Betain (s)	Cadaveric cleavage product
Cholin (1)	Cleavage product: animal & vegetable tissue
Hydroxycholine	Decaying fish
Secaline (g)	Putrefying cholin
Aminovaleric acid (1)	Decomposed meat
Creatoxin	Decomposed meat
Cadaverine (1)	Decomposed animal tissue
Putrescine (1)	Decomposed animal tissue
Caprylamine (1)	Rancid animal oil & yeast
Morrhuine (1)	Decomposed fish oil
Tyrotoxine (s)	Decomposed dairy foods
Diethylamine (1)	Decomposed fish
Triethylamine (1)	Decomposed fish
Collidine (1)	Putrefying fish

(s) solid (1) liquid (g) gas

(1) Ptomaines are also produced in putrefied flesh (Mydin & Mydatoxine), and from carbohydrates by the action of ammonia (Glycosins).

TABLE 59

TOXIC AND FOUL SMELLING VAPORS & GASES PRODUCED BY BACTERIAL DEGREDATION OF FOOD WASTES

Origin of Vapors & Cases	Odor
Ptomaines:*	
Cadaverine (animal tissue)	putrefactive
Aminovaleric acid (meat)	putrefactive
Caprylamine (animal oil)	foul
Secaline (animal tissue)	fishy
Triethylamine (fish)	fishy
Diethylamine (fish)	fishy
Tyrotoxine (dairy)	stale
Others:	
Indol (intestinal putrefaction)	fecal
Skatole (feces, putrefied albumins)	fecal
Butyric acid (oils, fats, cheese, sugar, starch)	rancid
Valeric acid (oils, meat)	caprylic
Ammonia (NH_3) (proteins)	ammonical
Hydrogen sulphide (H_2S) (sulphur-) (proteins)	foul egg
Mercaptans (–SH–)	foul
Carbon monoxide (CO)	(no odor)

*See also Table 58

from decaying organic matter is quite small. However, traces of odorous substances are sufficient to contaminate the air. Simple control measures such as good ventilation of the building can prevent the buildup of noxious gases and vapors. Ventilation of the storage areas for loose and uncompacted refuse, and around the press, could be used to remove the gases and vapors at their source.

Foul odors are not always emitted from wastes, since the main source, raw meat and fish scraps, are not always present. During a previous study,[17] it was found that compacted bales containing a high proportion of spring cleaning materials from gardens, decomposed appreciable without developing foul-smelling odors. Analysis of the gas samples and temperature taken at the time of sampling (Table 60) indicated that the bacterial activity was primarily aerobic. The collected gases contained mainly carbon dioxide; only traces of carbon monoxide and no methane was detected. The maximum temperature recorded was 129° for a bale compacted at 2,000 psi.

Leachings from Wastes during Compaction and in Landfills

Ordinarily, the amount of leachings extracted from household wastes, during compaction, is small. Extracts are not obtained from dry refuse. Wet refuse releases only part of its moisture, and as a result, an initially wet refuse remains wet after compaction. The leachings, which contain liquids, suspended solids, and a high proportion of sludge, tend to release very unpleasant odors if left to stand.

To avoid pollution of the working area by stagnant leachings, provision should be made to collect and dispose of the extracts below the press. Design provisions should also control the release of leachings, especially pulps, through tiny clearings at the top of the press. The latter type of extraction occurs only if the refuse is very wet. However, due to the buildup of pressure during compaction, the extract can be expelled with great force, and if not controlled, could be sprayed over a large area of the building.

An analysis of leachings was carried out during the City of Chicago compaction program, (Table 61). The results indicate that they are likely to contain mainly organic matter.

A microbiological analysis of press leachings, Table 62, also carried out during the City of Chicago compaction program, indicated the presence of only one pathogenic microorganism, a virus. Although the investigation was limited to leachings obtained from one load of refuse, the finding is in accordance with previous experience which indicates that disease-carrying microorganisms are, as a rule, not abundant in household wastes. Refuse-related

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[17] *Development and Testing of High-Pressure Compaction and Baling of Solid Wastes for Rail Haul*, City of Chicago, September 1969.

TABLE 60

GAS ANALYSIS AND BALE TEMPERATURE OF COMPACTED SPRING CLEANING RESIDENTIAL WASTES

Bales	Time of[1] Sampling (days)	Percent of Gas				Bale Temperature (°F)	
		CO_2	O_2	CO	CH_4	Inside	Surface
Residential – Loose (3500 psi)	4.5	7.0	13.1	0.009	none	105	95
	8	2.9	17.5	trace	"	102	93
Residential – Loose (2000 psi)	4.5	6.4	14.2	0.011	none	129	125
	8	7.3	12.4	trace	"	105	119
Papersacked (3500 psi)	4.5	4.2[2]	16.2	0.013	none	118	113
	8	4.5	15.6	trace	"	100	110
Papersacked (2000 psi)	4.5	–	–	–	none	115	103
	8	6.9	13.2	trace	"	115	103
Plastic Covered (3500 psi)	4.5	3.5	17.3	0.019	none	106	98
	8	3.7	16.7	trace	"	106	90
Plastic Covered (2000 psi)	4.5	7.6	12.4	0.013	none	97	93
	8	4.7	15.5	trace	"	92	89

[1] Time elapsed after bale was made.

[2] Mean value of both papersacked samples.

TABLE 61
CHEMICAL ANALYSIS OF LEACHINGS[1]

Sludge	**Sample 1**	**Sample 2**
Organic Matter	38.9%	76.7%
Silica as SiO_2	30.8	6.9
Aluminum as Al_2O_3	15.2	5.8
Phosphates as P_2O_5	8.9	4.4
Calcium as CaO	2.0	1.3
Magnesium as MgO	1.4	0.0
Iron as Fe_2O_3	0.5	0.6
Sulphates as SO_3	Trace	Trace
Carbonates as CO_2	0.0	0.0
Liquid		
pH	7.8	4.5
Total dissolved solids	6090 ppm	6040 ppm
Organic Matter	1720	4480
Bicarbonates	90	610
Sulphates	250	200
Chlorides	21	218
Heavy metals (suspension)	Large % amt.	Small % amt.

[1] *Development and Testing of High-Pressure Compaction and Baling of Solid Wastes for Rail Haul*, City of Chicago, September 1969.

TABLE 62
MICROBIOLOGICAL ANALYSIS OF LEACHINGS[1]

Bacteriology	
Aerobic plate count	8.3 x 10^6 organisms/ml.
Anaerobic plate count	7.7 x 10^6 organisms/ml.
Identified Bacteria (to genus)	1. Bacillus sp. 2. Coliform group 3. Streptococcus sp. (alpha hemolytic and non-hemolytic noted.) 5. Alcaligenes sp. 6. Micrococcus sp. (coagulese negative) 7. Flavobacter sp. 8. Aerobacter sp.
Yeasts	Yeast cells were observed
Molds	1. Penicillium 2. Streptomyces 3. Paecilomyces 4. Mucor
Parasitiology	A number of free living amoebae as well as ciliates were noted.
Water Bacteriology	
1. Standard plate count @ 35°C:	4.9 x 10^7 organisms/ml.
2. MPN technique:	9.2 x 10^8 organisms/100 ml.
3. Fecal streptococci (membrane filter)	7.0 x 10^6 organisms/100 ml.
4. Staphylococci (membrane filter)	5.7 x 10^7 organisms/100 ml.
Virology	Virus isolated and identified as ECHO by anti-serum neutralization
Chemistry	pH: 7; D.O.: none

[1] High Pressure Compaction and Baling of Solid Wastes, City of Chicago

epidemiological data presented in the next section show that the number of reported incidences of disease, related to loose household wastes, are limited. This is understandable since many pathogenes cannot survive outside their host organism. The environmental conditions for survival of pathogenes are even more unsuitable in the compacted bales than in loose refuse. As a result of the rapid development of high temperatures (see Table 60) during storage and transport, the landfill leachings from compacted bales should contain relatively few pathogenes.

Epidemiological Information on Disease Associated with Refuse and Selected Factors Affecting the Survival of Pathogenes

Previous experience on disease associated with refuse indicates that severe disease problems are not encountered in handling loose household wastes. A limited number of incidences of a variety of diseases have been reported, although definitive information is largely lacking. The possibilities of disease transfer by loose solid wastes has been discussed at length in a previous report,[18] but very little concrete supporting evidence has been developed.

To provide a basis for the evaluation of whether or not disease-carrying organisms are likely to be present in compacted bales, and to allow for future developments of handling loose wastes, an attempt was made during the present study to gather available epidemiological data and correlate these data with information on factors which affect the survival of pathogenes in refuse.

The epidemiological information presented in Table 63 relates to diseases which have been associated with loose refuse. Taken at its face value, it might suggest that Streptococal disease could be associated with refuse more often than any other disease. However, in the absence of well-documented studies it is not clear whether it is more prevalent. Nevertheless, it appears advisable that this disease, and at least those for which more than 10,000 cases from all sources, and comparatively high mortality rates for the total United States population have been reported, be investigated in more detail. Diseases, thus, suggested for further study include:

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[18] Hanka, Thrift G., *Solid Waste/Disease Relationships*. Public Health Service Publication No. 999 UIH-6, Cincinnati, 1967.

Streptococal disease,
Tuberculosis,
Infectious hepatitis,
Salmonellosis,
Shigellosis, and
Encephalitis.

Background information (see also Table 64) shows that streptococci are mainly transmitted by direct contact with human carriers and that casual contact rarely leads to infection. However, the disease also can be transmitted through indirect contact with contaminated objects, although if the Streptococci are dried they do not produce infection. The *tubercle bacillus* is found to be more resistant to environmental factors than many other human pathogenes. It is resistant to drying. It can remain viable for many months in water and food, and in the dry state, if surrounded by organic matter such as paper, is resistant to dry heat at 100°C up to 45 minutes. However, it is easily killed by sunlight and UV radiation. The hepatitis virus appears to be affected by seasonal influence. Increases in incidences of the disease have been reported during autumn and winter. Salmonella bacteria have been found to be only moderately viable outside the human body, however, these organisms survive and multiply considerably in food. Shigella bacteria are easily killed by drying, chemicals, and sunlight. They are found to survive for months in water and for days in soiled bedding and textiles.

Encephalitis viruses have been associated with refuse; however, no specific data on their viability other than indicated in Table 64 have been found.

The information given in Table 64 has been developed with a dual purpose. One, to provide input data on the resistance of pathogenes in loose refuse and two, to evaluate the survival possibility of pathogenes, associated with loose refuse, in compacted bales. Only the resistance to temperature, moisture and the refuse media in which the organisms could survive are listed. Other factors, such as pH and light, have not been considered primarily because only small portions of refuse are exposed to sunlight and the pH of refuse can vary from load to load. The information on pathogene destruction as a function of temperature and time has been specifically selected because of its relevance to rail-haul.

Experiments carried out during the High-Pressure Compaction program showed that the temperature of compacted bales rises rapidly after compaction and that it remains high over a period of days. The maximum temperature recorded after a lapse of 4.5 days was about 50°C. In addition, it was found, both during storage and during transport, that the rise in temperature was accompanied by the development of a large quantity of moisture. Since the destruction of microorganisms is appreciably more effective with moist heat than with dry heat, the generation of moisture in the bales has a beneficial effect.

The thermal-death-time data given in Table 61 indicate the interrelationship between temperature and time of exposure. It should be recognized that the values recorded are those reported in the indicated references and that other values have been obtained mainly as a result of variations of factors such as nature of the medium, number of organisms, and pH. However, the resistance to temperature and moisture, as given, is sufficiently accurate for the evaluation purposes of this report. It should be recognized also that the destruction of organisms can be accomplished at lower temperatures than indicated, if the time of exposure is increased.

As shown in Table 64, most of the agents of diseases associated with wastes are destroyed at about 55° to 60°C in *30 minutes*. Experience with compacted bales indicates that the highest temperatures generated in the bales is likely to be in the vicinity of the above figures. In addition, the temperature in stacked or enclosed bales was found to rise more rapidly and to remain relatively high over a long period of time (see Table 60). Since the temperature requirement is lowered as the time of heat exposure is increased, and since the bacterial action in the bales generates not only heat but also moisture, it can be concluded that bales compacted at high pressures provide a most suitable environment for killing pathogenes.

TABLE 63
EPIDEMIOLOGICAL INFORMATION CONCERNING DISEASES ASSOCIATED WITH SOLID WASTES

Disease	Agents	Incubation Period	Incidence-Mortality (1966)	(1965)	Important Vector	Source & Mode of Transmission
Streptococal disease (includes sore throat & scarlet fever)	Streptococcus pyogenes 40 different serotypes	1-3 days	427,752	63		Contact with contaminated objects Inhalation of contaminated dust
Tuberculosis	Mycobacterium tuberculosis	Maybe yrs. 6 to 12 mos. after infection is most hazardous	47,767	7,938	Flies	Airborne dust Contaminated articles Human fecal waste
Infectious hepatitis	Virus	15-50 days Commonly 25 days	32,859	707	Flies	Feces Contaminated milk, food (contact) Contaminated dust
Salmonellosis	Salmonella numerous	5-48 hrs. Usually 12-24 hrs.	15,841	87* *(includes paratyphoid)	Flies	Food: meat, sausage, poultry or poultry products; milk or dairy products Animal feces
Shigellosis	Serotypes of genus shigella bacteria	1-7 days Usually less than 4 days	11,888	99	Flies	Feces Objects soiled with feces Contaminated foods, water, milk
Acute conjunctivitis	Haemophilus aegyptus H. influenzae Moraxella lacunata Staphylococci Streptococci C. diphtheriae	24-72 hrs.	7,072 (25 states)		Eye gnats or Flies	Contaminated objects

Table 63 (Continued)

Disease	Agents	Incubation Period	Reported Incidence-Mortality (1966)	(1965)	Important Vector	Source & Mode of Transmission
Hookworm disease	Necator americanus	6 wks. (for egg to appear in feces)	3,756 (10 states)			Feces larvae: penetrate skin
Staphylococcal disease	Staphylococci bacteria (many strains)	4-10 days	3,522 (6 states)		Flies (not proven)	Contact with contaminated objects Airborne dust
Amebiasis	Entamoeba histolytica	5 days to seven mos. Commonly 3-4 wks.	2,921	66	Flies	Contaminated vegetables Human and dog feces
Encephalitis	Eastern Equine Western Equine	5-15 days	2,121	500	Mosquitos Birds	Bit of mosquitos
Trachoma	The filterable agent of trachoma A Bedsonia	5-12 days	1,165 (8 states)		Flies	Materials contaminated with occular discharges
Coccidiomycosis	Coccidioides immitis	10 days to 3 weeks	347 (10 states)	52		Inhalation of spore laden dust: soil, dry vegetation
Ascariasis	Ascaris lumbricoides	2 mos.	451 (6 states)		Flies	Transmission of embryonated eggs in soil Dust Human fecal waste
Typhoid Fever	Salmonella typhi	1-3 wks	378	6	Flies	Contaminated food: raw fruits, vegetables, milk, milk products, shellfish Contaminated human fecal waste

Table 6.3 (Continued)

Disease	Agents	Incubation Period	Reported Incidence-Mortality (1966)	(1965)	Important Vector	Source & Mode of Transmission
Schistosomiasis	Schistosoma mansoni	4-6 wks (288-N.Y.City, 1-New Mexico)	289		Snail	Contaminated human fecal wastes
Rocky Mountain Spotted Fever	Rickettsia rickettsii	3-10 days	268	16	Dermacentor variabilis D. Anderson Amblyomma americanum	Contact with crushed tissues or feces of tick
Brucellosis	Brucella melitensis B. Abortus B. suis		262	6	Flies	Infected tissues or animal secretions; milk and dairy products
Histoplasmosis	Histoplasma capsulatum	5-18 days Commonly 10 days	236 (10 states)	74		Inhalation of spore laden dust Ingestion of spore contamianted foods
Tularemia	Pasteurella tularensis	1-10 days Usually 3 days	208	2	Rats Flies Ticks Mosquitos	Infected animals (contact)
Trichinosis	Trichenella spiralis	2-28 days Usually 9 days	115	3		Contaminated flesh of animals
Poliomyelitis	Poliovirus types 1, 2, 3	7-12 days	113	16	Flies	Contaminated milk Human feces
Coxsackie virus	Virus		51 (3 states)			

Table 63 (Continued)

Disease	Agents	Incubation Period	Reported Incidence-Mortality (1966)	(1965)	Important Vector	Source & Mode of Transmission
Cryptococcosis	Cryptococcus neoformans	No data	31	62		Inhalation of spore laden dust
O Fever	Rickettsia burneti	Usually 2-3 wks.	21 (5 states)		Flies	Airborne dust Infected milk
North American Blastomvcosis	Blastomyces dermotitidis	Few weeks	19 (47 states)	29		Inhalation of resistant spores in spore laden dust
Anthrax	Bacillus anthracis	4-7 days	5	0	Flies	Products of infected animals (contact) Contaminated meat ingestion
Larva Migrans visceral	Toxicana canis or Toxicana cati	weeks or mos.	2 (1 state)			Embryonated eggs in soil
Lumphocytic choriomeningitis	The virus of lymphocytic choriomeningitis	8-13 days 15-21 days (meningeal symptoms)	rare		Anthropods Mice	Contaminated food
Enterobiasis	Enterobius vermicularis	3-6 wks.			Flies	Dustborne inhalation
Diphyllobothriasis	Diphyllobothrium latum	3-6 wks.			Flies	Raw or inadequately cooked fish
Paratyphoid Fever	Salmonella paratyphi	1-20 days	* *Included in Salmonellosis		Flies	Food, milk, shellfish
Taeniasis and Cysticercosis	Tagenia solium Taenia saginata	8-10 wks.			Flies	Raw or inadequately cooked beef, pork Infected feces
Strongyloidiasis	Strongyloides stercoralis	17 days (for larvae to appear in feces)				Filariform larvae in feces penetrate skin

TABLE 64

SELECTED FACTORS OF SIGNIFICANCE IN THE CONTROL AND SURVIVAL OF PATHOGENIC ORGANISMS ASSOCIATED WITH REFUSE

Pathogenic Organisms	Resistance			Media in which Pathogen is is likely to survive
	Temperature – Time Thermal Death Point (TDP) Thermal Death Time (TDT)	Refs.	Moisture	
Streptococcus pyogenes (Bacteria)	Some varieties: TDP at 55°C in 10 min. Practically all species: TDP at 60°C in 30-60 min. Pasteurization of milk: TDP at 62°C in 30 min.	11	Survives for days in dust, especially if protected from sunlight. (Ref. 10) Dried streptococci though viable do not produce infections. (Ref. 2)	Contaminated food, bedding, clothing, dust. (Ref. 7) Streptococci usually grow best at a pH between 7.4 and 7.6 (Ref. 11) Optimum growth temperature: 37.5°C.
Mycobacterium tuberculosis	Moist heat: TDP at 60°C in 15-20 min.	10	Resistant to drying (Refs. 10, 2, 4, 11)	Dried sputum, food, paper. (Refs. 10, 2, 4, 11)
Infectious hepatitis (filterable virus)	Survives heating at: 56°C for 30 min. Survives in frozen feces at: −10°C to −20°C for 1½ years Inactive at: −70°C after 32 months	6	No data	Human feces and blood. (Ref. 6)
Salmonella (Bacteria)	Readily destroyed by pasteurization at: 60°–63°C	4	No data	Capable of considerable multiplication in bland and moist food. (Ref. 4)
Shigella (Bacteria)	Easily destroyed by pasteurization TDP at 55°C in 1 hour	11 10	Killed in few min. by drying. (Ref. 2) Viable in water for months. (Ref. 11)	Water or mucoid discharge Remains viable on clothing for many days. (Ref. 11)
Haemophilus aegyptus H. influenza Moraxella lacunata (Bacteria)	TDP at 55°C for 30 min.	5	Rapidly killed by dessiccation. (Ref. 11)	No data
Necator americanus (Helminth)	Below 70°F and above 85°F development is retarded. It is never complete at 45°F.	2	Hookworm disease is endemic only in regions where the rainfall averages 50 or more inches per year. (Ref. 7) Drying rapidly destroys larva and even the eggs. (Ref. 2)	Feces, damp textiles (Ref. 2) Optimum growth temperature:– 75° to 85°F

Table 64 (Continued)

Pathogenic Organisms	Resistance			Media in which Pathogen is likely to survive
	Temperature – Time Thermal Death Point (TDP) Thermal Death Time (TDT)	Refs.	Moisture	
Staphylococci (Bacteria)	TDP 62°C for 30 min. Some strains resist: 80°C for 30 min. Resist freezing	10 12 10	May survive for many months in dust (resists drying) (Ref. 10)	Ubiquitous, e.g. threads, paper, cloth, pus. (Ref. 11) Dust (Ref. 10)
Entamoeba histolytica (Protozoa cysts)	Resists freezing up to 1 year TDP at 20° to 25°C in a few wks Rapidly killed at 55°C.	2	Quickly killed by drying (Ref. 2) Survives in water. (Ref. 2)	Water – no data on feces. Resists chlorination
Eastern equine Western equine Japanese B Murray Valley (Viruses)	Viability of the virus depends on that of the tick.		No data	No data
Trachoma (Filterable Virus)	TDP at 45°C in 15 min. Inactivated by freezing	6 6	No data	Mucoid discharges (Ref. 3)
Coccidicides immitis (Spore-forming fungus)	Resistant at: 80°–90°F; and 39°–53°F	9	Highly resistant to drying. (Ref. 11) Rainfall of 5–20 in. per yr. is favorable (Ref. 9)	Soil, moisture, dust (Ref. 9)
Ascaris lumbricoides (Helminth)	Resistant below 70°C Resists freezing	7 2	Resists desiccation. (Ref. 2) Viable in water (Ref. 2)	Feces, soil. (Ref. 2)
Salmonella typhi (Bacteria)	TDP ~56°C Resists freezing	10 2	Not resistant to drying. (Ref. 2) Seldom survives longer than a week in water. (Ref. 2)	Feces may provide some protection (Ref. 2)
Schistosoma mansoni S. haemotosium S. japonicum (Trematoide worms)	No data		No data	Various mamals, birds, snails. Human feces and urine. Contaminated water. (Ref. 8)

Table 64 (Continued)

Pathogenic Organisms	Resistance			Media in which Pathogen is likely to survive
	Temperature – Time Thermal Death Point (TDP) Thermal Death Time (TDT)	Refs.	Moisture	
Richettsia richettsii (Intermediate between smaller bacteria and larger viruses (Ref.10)	Viability is dependent upon that of the ticks		No data	Feces and tissue of ticks
Brucella melitensis B. abortus B. suis Melitensis abortus (Bacteria)	TDP at 55°C in 1 hour TDP at 58°C in 10-15 min. All killed at 60°C. Resists freezing	 2 11	Resistant to drying; may survive 1 month in dust; survives in water. (Ref. 2)	Cheese; milk, dust, water, backyard soil (Refs. 7,2)
Histoplasma capsulatum (spore-forming fungus)	Excessive temperature changes may limit infection	13	Rainfall of 35–50 inches per year is associated with survival. (Ref. 13)	Bird manure. (Ref. 2) Moisture. (Ref. 13)
Pasteurella tulerensis (Bacteria)	TDP 56°C in 10 min. Resists freezing	5 5	Survives in water. (Ref. 4)	Rabbit carcasses. (Ref. 4)
Trichinella spiralis (Helminth)	TDP at 58°C in few min. Refrigeration at 5°F for 20 days at –10°F for 10 days at –20°F for 6 days is considered an effective safeguard	4 2	No data	Infected pork and pork products (Ref. 2)
Poliovirus (types 1, 2, 3) (Viruses)	Inactivated by heating at: 55°C for 30 min. Resists freezing	6 6	Inactivated by drying. (Ref. 6) Survives in water (Ref. 6)	Human feces. (Ref. 6)
Coxsackie (Virus)	Survives 55°C for 30 min. TDP at 60°C after 30 min. Resists freezing.	11 6,11	Resembles poliomyelitis virus in its resistance to physical and chemical agents. (Ref. 6)	Feces; can survive over a wide range of pH.

Table 64 (Continued)

Pathogenic Organisms	Resistance			Media in which Pathogen is likely to survive
	Temperature – Time Thermal Death Point (TDP) Thermal Death Time (TDT)	Refs.	Moisture	
Cryptococcus neoformans (spore-forming fungus)	TDP at 60°C in 5 min.	11	Resistant to drying at room temperature for several months. (Ref. 11)	Soil, dust. (Ref. 10)
Coxiella burneti (Rickettsia)	Can withstand 60°C for 1 hour	5	Survives for years in dried tick feces. (Ref. 5) Viable in water. (Ref. 10)	Tick feces. (Ref. 5) Dust
Blastomyces dermatitidis (spore-forming fungus)	TDP at 56°C in 60 min.	11	No data	Dust
Bacillus anthracis (spore-forming bacteria)	Highly resistant to dry heat 140°C for 1–3 hours Resists moist heat: 100°C for 2–15 min. Resists freezing	10	Viable for many years in soil (Ref. 3)	Products of animal hides and hair. (Ref. 2) Optimum survival temperature
Toxicana canis or Toxicana cati (Helminth)	Eggs highly resistant to desiccation	2	No data	Feces of dog and cat. (Ref. 2) May survive for years in soil
Virus of lymphocytic choriemeningitis	Survives at –70°C at least a year TDP at 55°C in 20 min.	6	No data	Dust, contaminated food (Ref. 6)
Enterobius vermicularis (Helminth)	No data		No data	Dust, clothing, bedding, food. (Ref. 3)

APPENDIX C

EXAMPLES OF POTENTIAL RAIL-HAUL SANITARY LANDFILL DISPOSAL SITES

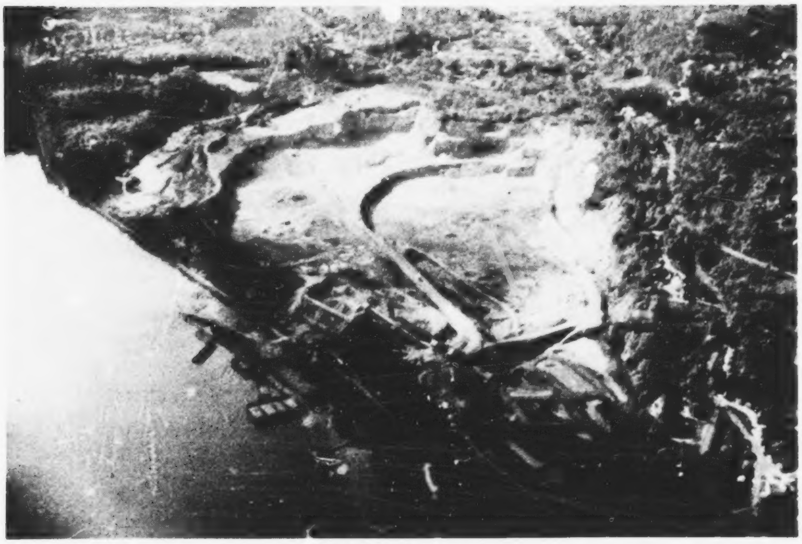
Photo-survey flights were made on the Penn Central trackage in several states. The altitude of the aircraft varied from 500 to 2,500 feet above local terrain and all photographs were taken with hand-held 35 mm cameras. Flight planning and location plotting were performed on the latest available U. S. Geological Survey, 7 1/2 minute and 15 minute series, topographic maps, which have scales of 1:24,000 and 1:62,500, respectively. Metropolitan areas were avoided.

Sites which met the selection requirements were observed and photographed during the reconnaissance. These requirements included.

1. Proximity to the rail line, existence of a rail spur, or reasonable terrain features to construct a spur.
2. Sufficient site size to assure use over a period of time or the capability of considerable expansion.
3. Density of population in the immediate site locale.
4. Screening of the site by natural vegetation and landform features.
5. Availability of sufficient cover material for back-filling the site.
6. Consideration of local water features and water table in regard to possible pollution.
7. Local road pattern and general transportation network.
8. Social features such as reservoirs, cemeteries, schools, etc., which could cause political and public relations problems.

Soil and geological structure factors were considered to the extent observable from the air and interpretable from the maps, tempered by the capabilities of the survey personnel. "On-the-ground" observations of these factors would, of course, be made by more experienced and competent personnel. It was observed that the water table could present a problem in many of the areas surveyed.

Four examples are given from the surveys of the states of New York, Michigan and Ohio to give an indication as to the various types of potential sites which are within convenient rail-haul distance of major urban areas and served by just one carrier. Location and ownership have not been detailed, rather the information is given only for the purpose of illustrating types of facilities which would be considered for a rail-haul project.



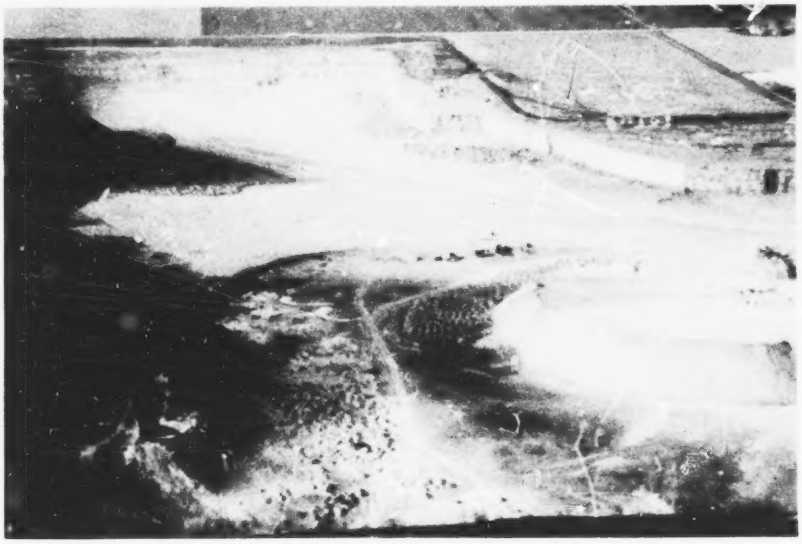
EXAMPLE 1

Description: Quarry

Location: This active quarry is adjacent to the Penn Central mainline and the Hudson River.

Preliminary Analysis

This large quarry measures approximately 4,000 x 2,000 feet at its widest points. The site is also quite deep and well screened by trees. Cover material is readily available and water should cause no problems. The site also appears capable of expansion to the North and South. A loading facility capable of serving both rail and water transportation systems is currently in operation.



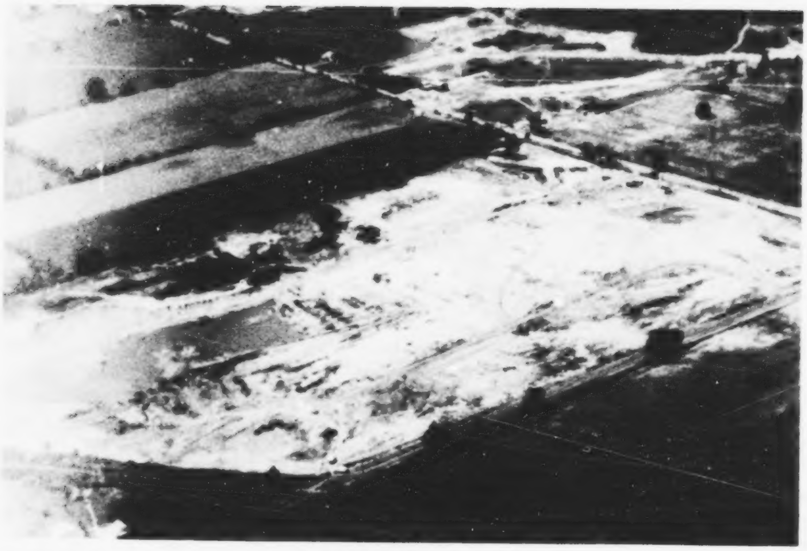
EXAMPLE 2

Description: Group of Quarries

Location: These large, deep, active quarries are located on the Penn Central mainline.

Preliminary Analysis:

This group covers an area measuring approximately 1 mile x 3/4 mile at its widest points. They are not screened by trees, but cover material should be available. The site is served by several rail spurs from the mainline. Expansion may be possible to the North and water does not appear to present a problem.



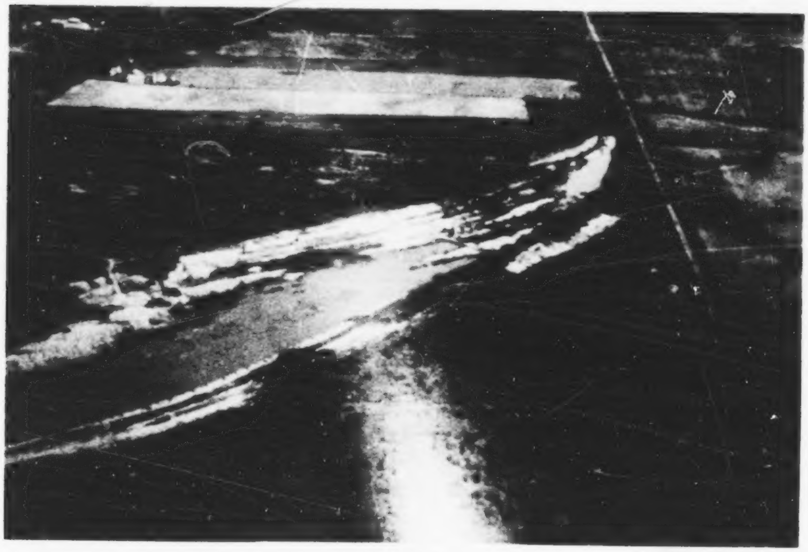
EXAMPLE 3

Description: Claypit

Location: On a spur of the Michigan Central trackage.

Preliminary Analysis

This partially water-filled pit appears to be abandoned. The site is fairly well screened by trees and cover material should be abundant. The immediate locale is sparsely populated. The rail spur from the Michigan Central line is approximately 3,500 feet long extending nearly the full length of the pit. Damming the nearby drain could alleviate the water problem.



EXAMPLE 4

Description: Sanitary Landfill

Location: Railroad Branch line

Preliminary Analysis

This appears to be a large working sanitary landfill for a[medium-sized]city. The site is ideal from a number of points of view:

1. Zoning is an accomplished fact
2. Operation is currently under way
3. The area is rural in character
4. The railroad is a branch line with daily service which should allow easy operation.
5. The property seems capable of expansion

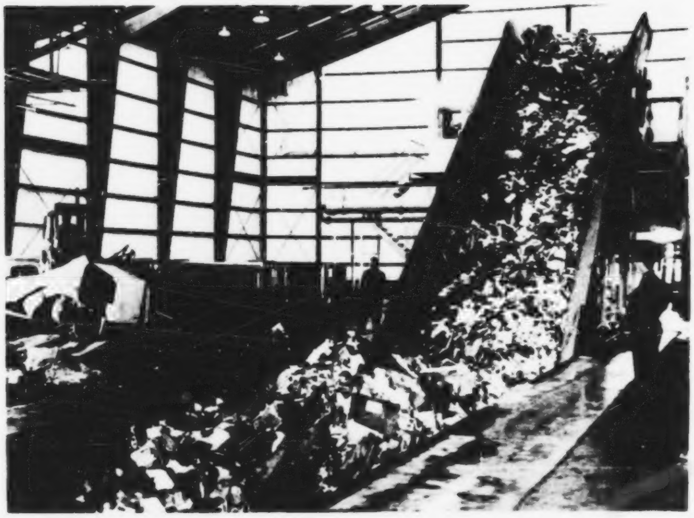
APPENDIX D

PHOTOGRAPHS OF BALED SOLID WASTES AND SANITARY LANDFILL OPERATIONS WITH BALED WASTE

Throughout the study of the feasibility of rail-haul of solid wastes and the study of high-pressure compaction and baling of solid wastes, considerable interest was exhibited by various private industries. Several press manufacturers helped to evaluate the experimental press; the comments beginning on page 37 of the report were derived from their evaluations.

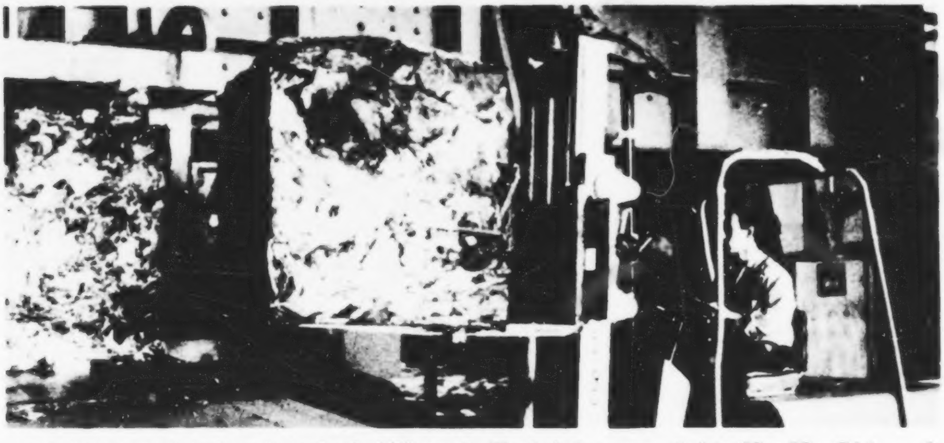
Two baling facilities began operating in 1971: a plant built by Reclamation Systems, Inc., of Boston, Mass., was opened early in the year, and American Solid Waste System later opened a facility in the Minneapolis-St. Paul, Minn., area.

The four photographs on these pages show American Solid Waste System's operation – from receipt of refuse, to weigh hopper used to charge the baler, to sanitary landfill composed entirely of baled refuse. This full-size facility has independently demonstrated the feasibility of baling as a processing step that makes possible the economics of handling and movement as described in this report.



1. An 8-ft. wide conveyor carries refuse to the baler weigh hopper. A dozer (left rear) pushes aside salvageable metal for baling and recycling.

2. Weigh hopper dumps 2,500–2,700 lb. of refuse into charge box for three-stroke compression. Final stroke is held 8 sec. to eliminate air pockets, reduce spring back. Entire process takes 90 sec.



3. Bale being taken from baler by forklift truck. The bale has expanded to 38 x 38 x 51 in. and weighs 2,700 lb. Bales also can be handled by tongs, overhead crane, and conveyors.

4. Transfer truck unloads bales on table at left. Two levels have been placed in landfill site.

5. Dozer pushes bales into place atop earlier layer that has been covered with earth taken from slope in background.

6. Closeup shows that bales retain shape without strapping or adhesives. Loose, blowing refuse is minimal.